Asymmetric Patterns of Visual Field Loss in Primary Angle Closure Glaucoma, High Tension Glaucoma, and Normal Tension Glaucoma

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Abstract

The data directly comparing the spatial pattern of VF defects between primary angle-closure glaucoma (PACG), high-tension glaucoma (HTG) and normal-tension glaucoma (NTG) is not available. We aim to compare the asymmetric patterns of VF defects in patients with PACG, NTG and HTG across different severity levels. A total of 162 eyes of 114 patients with PACG, 111 eyes of 74 patients with HTG and 148 eyes of 102 patients with NTG were included. VF examinations were performed with standard automated perimetry (HFA, SITA-standard strategy, 24-2), and defects were categorized into 3 stages (early, moderate, and advanced) and each hemield was divided into 5 regions according to Glaucoma Hemield Test (GHT). The mean total deviation (TD) of each GHT region was calculated. The relationship between the values of pattern standard deviation (PSD) and mean TD was assessed. In the early stage, nasal region of PACG, central region of HTG and all 5 regions of NTG in the superior hemield had significantly worse mean TD than their counterparts in the inferior hemield. In the moderate stage, three regions of NTG in the superior hemield had significantly worse mean TD than their inferior counterparts. In the advanced stage, central region of PACG, and central and paracentral regions of HTG in the superior hemield had significantly worse mean TD than their inferior counterparts. When participants were matched by age, sex and mean deviation, in PACG and HTG eyes, all 5 GHT regions in the superior hemield had worse mean TD than that of their inferior-hemield counterparts; however, the differences were not statistically significant. In NTG eyes, the paracentral, nasal, arcuate 1 and arcuate 2 regions in the superior hemield had significantly worse mean TDs than their inferior counterparts. The superior hemield is affected more severely than the inferior hemield in all 3 subtypes of primary glaucoma. This asymmetric tendency was more pronounced in NTG compared to PACG and HTG.

Introduction

Glaucoma is the leading global cause of irreversible blindness, affecting 79.6 million people worldwide in 2020.\(^1\) It is a progressive optic neuropathy with characteristic structural changes and corresponding visual field (VF) defects.\(^2\) Primary glaucoma is divided into primary angle-closure glaucoma (PACG) and primary open-angle glaucoma (POAG) based on the status of the iridocorneal angle.\(^3\) And POAG is subdivided into high-tension glaucoma (HTG) and normal-tension glaucoma (NTG).

PACG, with a crowded anterior segment and narrow anterior chamber angle, is characterized by elevated IOP secondary to the mechanical obstruction of the aqueous outflow by apposition of the iris to the trabecular meshwork.\(^4\) Pressure-dependent damage is considered to be the major pathogenesis of glaucomatous optic neuropathy in PACG.\(^4\) By comparison, the mechanism of optic nerve damage in HTG is thought to be a mixture of pressure-dependent and pressure-independent causes. Besides IOP, there are other factors believed to be involved in the development and worsening of HTG, such as choroidal blood flow, vascular dysregulation, and low cerebrospinal fluid pressure.\(^5-7\) The pressure-independent vasogenic risk factors are considered to be more important in the development and progression of NTG as compared to HTG.\(^6, 8, 9\)

The difference between PACG, HTG and NTG also reflects genetic associations, and glaucomatous structural and functional damage. The genetic associations differ between PACG, HTG and NTG. The MYOC\(^10\) and CAV1/CAV2\(^11\) loci have been found to be associated with HTG, and the OPTN gene with NTG,\(^12\) while COL11A1, PCMTD1 and ST18\(^13\) are associated with PACG. The morphometric features of glaucomatous optic nerve head (ONH) damage also differ between PACG, HTG and NTG. Eyes with NTG tend to have a greater degree of rim thinning, larger cup areas and cup/disc ratios and smaller rim area than eyes with HTG\(^14, 15\) and PACG\(^16\). Smaller optic discs with smaller cup areas and larger rim area are presented in PACG than in HTG eyes.\(^17\)

The characteristics of the visual field damage in POAG have been previously reported by several studies using Goldmann perimetry: visual field defects in NTG were found to be more central,\(^18, 19\) more localized,\(^20-22\) steeper\(^18, 19, 23\) and more commonly in the superior hemield than in HTG.\(^24\) In comparison, published data on VF damage in PACG is relatively limited.\(^25\) The differences between VF defect in PACG, NTG and HTG have been reported by several studies utilizing automated perimetry: in both PACG and HTG, the superior hemield is more severely affected than the inferior hemield,\(^26, 27\) and the VF defects in HTG as compared to PACG tend to be more localized.\(^26, 28\) However, each of these studies included only one or two types of glaucoma, only one prior small study has directly compared the interocular asymmetry of the VF defects between eyes with NTG, PACG and
HTG, and one study has compared the VF progression rates among these 3 glaucoma subtypes. The data directly comparing the spatial pattern of VF defects between PACG, HTG and NTG is not available. We therefore compared the asymmetric patterns of VF defects in patients with PACG, NTG and HTG across different severity levels.

Methods

Participants

In this cross-sectional study, patients diagnosed with HTG and PACG by a glaucoma specialist (Y.B.L.) were recruited from the glaucoma clinic of the Eye Hospital of Wenzhou Medical University from January 2017 to December 2019. Patients with NTG were recruited from the Wenzhou Glaucoma Progression Study (WGPS), a longitudinal community-based study providing free glaucoma screenings in the Wenzhou area. Written informed consent was obtained from all participants. The current study was approved by the Ethics Committee of the Eye Hospital of Wenzhou Medical University, and adhered to the tenets of the Declaration of Helsinki.

All participants in the current study had PACG, NTG or HTG. PACG was defined as the presence of angle closure together with evidence of glaucomatous optic neuropathy and corresponding VF defect, while angle closure was the inability to visualize the posterior trabecular meshwork for >= 180° on gonioscopy. HTG was defined as the presence of an open anterior chamber angle as assessed by gonioscopy, a single intraocular pressure (IOP) measurement > 24 mmHg, and evidence of glaucomatous optic neuropathy and a corresponding VF defect. NTG included an open anterior chamber angle as assessed by gonioscopy, the presence of glaucomatous optic neuropathy with corresponding VF defect, six median untreated IOP measurements consistently < 21 mmHg, with no single measurement > 24 mmHg and no more than one reading equal to 23 or 24 mmHg. Glaucomatous optic neuropathy was defined as the presence of any of the following: optic disc hemorrhage, retinal nerve fiber layer (RNFL) defect, vertical cup-to-disc ratio > 0.7 and/or CDR asymmetry > 0.2 or neuroretinal rim width <0.1.

Additional inclusion criteria were as follows: age >= 18 years, presenting visual acuity >= 6/18, and spherical equivalent (SE) refractive error between -6.0 and +3.0 diopter (D). Patients were excluded if they had secondary glaucoma, previous laser or incisional surgery of the retina, and/or other conditions potentially affecting the visual field.

Each potential participant underwent a comprehensive ophthalmic examination by a certified ophthalmic technician, including assessment of presenting visual acuity, refraction, IOP, slit-lamp biomicroscopy, gonioscopy, fundus photography (Visucam 200; Carl Zeiss Meditec, Inc., Dublin, CA, USA), and standard automated perimetry (Humphrey Field Analyzer [HFA] II; Carl-Zeiss Meditec, Inc.). IOPs were measured between 8:00 AM and 5:00 PM on one day and the median of two readings was used.

Visual field (VF) examinations were performed with the white-on-white 24-2 Swedish Interactive Threshold Algorithm (SITA) program. VF tests with fixation loss rates < 20% or false-positive and false negative error rates < 15% were considered reliable and eligible for analysis; the first VFs test for each participant was excluded from analysis.

VF severity was categorized into 3 stages based on the mean deviation (MD): early glaucoma (>= -6 dB), moderate glaucoma (< -6 dB and > -12 dB), advanced glaucoma (<= -12 dB). To evaluate the pattern of VF defects, the probability plot was divided into 5 subfield regions in each of the superior and inferior hemifields: central, paracentral, nasal, and two peripheral (arcuate 1 and arcuate 2), derived from the Glaucoma Hemifield Test (GHT). When recording pointwise data and dividing regions, VF tests of left eyes were inverted to resemble a right eye for ease of comparison. The mean total deviation (TD) values and mean pattern deviation (PD) values of the 10 visual field regions were calculated, including both superior and inferior hemifields.

Statistical Analysis

Generalized estimating equation (GEE) models were used to adjust for correlations between the two eyes of a participant and clustering within study groups in comparing demographic characteristics. For the pointwise analysis, the mean TD value of each VF test point in the superior hemifield was compared with its corresponding point in the inferior hemifield at each severity level for the three glaucoma groups using GEE model, accounting for mean TD. For the region-wise analysis, the mean TDs and mean PDs of the 5 GHT regions in the superior hemifield were compared with their counterparts in the inferior hemifield at each severity level.
for the three groups using the GEE model, adjusting for mean TD/PD and sex. The relationship between TD and PSD was compared in the three groups analyzed using GEE models. Statistical significance was set at P<0.05, and all analyses were performed using SPSS software version 21.0 (IBM, Chicago, IL) and “R” software (R version 4.0.2).

**Results**

**Comparisons Between Glaucoma Sub-type**

One hundred and sixty-two eyes of 114 participants with PACG, 111 eyes of 74 participants with HTG and 148 eyes of 102 participants with NTG were enrolled in this study. (Table 1) Participants with HTG were significantly younger than those with NTG and PACG (HTG vs. NTG, P =0.012; HTG vs. PACG, P <0.001). There were more women than men in the PACG and NTG groups, while there were more men in the HTG group. The mean SE refraction in the PACG group was significantly more hyperopic (positive) than that in the NTG and HTG groups (both P <0.001). The mean IOP in the NTG group was significantly lower than that for the HTG groups (P <0.001). LogMAR VA in the PACG group was significantly better than that for the NTG group (P<0.001).

In the early and moderate stages, there was no significant difference in the MD and mean TD among PACG, NTG and HTG eyes. In the advanced stage, the MD and mean TD of HTG and PACG group were significantly worse than that for the NTG group (all P <0.05). There were no significant differences in age and gender across early, moderate, and advanced severity levels among PACG, HTG and NTG group (Table 1). In the PACG group, VA was worst and IOP was highest in the advanced stage (all P <0.05); SE was similar across the severity levels. In the HTG and NTG groups, VA, IOP and SE was similar across the severity levels.

A total of 48 triplets were eyes included in each glaucoma subtype matched based on their age, sex, MD. There was no significant difference in age, sex, MD or degree of VF loss between the PACG, HTG and NTG groups (P = 0.154, 0.310, 0.272, 0.644, respectively, Table 2).

**Comparisons Between Hemifields**

In the early stage, the mean TD of the superior nasal region in the PACG group was significantly worse than its counterpart in the inferior hemifield (P =0.032, Table 3, Fig. 1-A). However, there was no significant difference between the hemifields in the remaining four regions. In the early stage of the HTG group (Fig. 1-D), the central region in the superior hemifield had significantly worse mean TD than its inferior counterpart (P =0.022); the remaining four regions showed no significant difference between the hemifields. In the early stage of the NTG group, all five GHT regions in the superior hemifield had significantly worse mean TD than their inferior counterparts (Fig. 1-G). In the moderate stage, three superior hemifield regions (nasal, central, and peripheral arcuate 2) of the NTG group also had significantly worse mean TD than their corresponding regions in the inferior hemifield (all P <0.05, Fig. 1-H). There was no significant difference in these mean TD of the five regions between the hemifields in both the moderate stage of the HTG and PACG groups (all P >0.05, Fig. 1-B, E). In the advanced stage, the superior hemifield central region of the PACG group had significantly worse mean TD than its inferior counterpart (P <0.001, Fig. 1-C); in the advanced stage of the HTG group, both central and paracentral regions in the superior hemifield had significantly worse mean TD than those in inferior hemifield (P =0.015 and P =0.045, respectively, Fig. 1-F). There was no significant difference in the mean TD for any of the five regions between the hemifields in the advanced stage of the NTG group (Fig. 1-I). The mean TD was significantly worse in the superior hemifield for early and moderate stages in the NTG group (all P <0.05), while there was no significant difference between the hemifields across the severity levels in either the PACG or HTG groups.

In the early stage, one point of the paracentral region, one point of the peripheral (arcuate 1) region and one point of the nasal region in superior hemifield had significantly worse TD than their inferior counterparts in the PACG group. (Figure 2) In the early stage of the HTG group, one point of the nasal region, one point of the central region and a point in the region adjacent to the blind spot had significantly worse mean TD than one in the inferior hemifield. In the early stage of the NTG group, several points clustering in the nasal, paracentral, peripheral (arcuate 1) and peripheral (arcuate 2) regions had significantly worse TD than their inferior counterparts. In the moderate stage, one point in the nasal, paracentral and peripheral (arcuate 1) region, and a point in the region adjacent to the blind spot in superior hemifield had significantly worse mean TD when compared with their counterparts in the inferior hemifield in the PACG group. In the moderate stage of the NTG group, several points clustering in the
nasal, central, peripheral (arcuate 1) and peripheral (arcuate 2) regions in superior hemifield had significantly worse mean TD than their inferior counterparts. In the advanced stage, several points clustering in the central and paracentral regions in the superior hemifield had significantly worse mean TD than their inferior counterparts in the PACG group. In the advanced stage of the HTG group, several points clustering in the nasal, central, and paracentral regions had significantly worse mean TD than their inferior counterparts.

Figure 3 shows the comparisons between the superior and inferior hemields for the matched subjects. The mean TD of the superior hemifield, as a whole, was worse than that of the inferior hemifield, and this difference was more significant in the NTG eyes (P = 0.243, 0.250 and 0.002 for PACG, HTG and NTG, respectively). In PACG and HTG eyes, all 5 GHT regions in the superior hemifield had worse mean TD than that of their inferior-hemifield counterparts; however, the differences were not statistically significant (all P > 0.05, Fig. 3-A, B). In NTG eyes, the paracentral, nasal, arcuate 1 and arcuate 2 regions in the superior hemifield had significantly worse mean TDs than their inferior counterparts (P = 0.045, 0.003, 0.007 and 0.001, respectively, Fig. 3-C).

In PACG eyes, a point in the region adjacent to the blind spot had significantly worse TD than its counterpart in the inferior hemifield (TD and P-values are shown in Fig. 3-D). In HTG eyes, 1 point of the nasal region, 1 point of the arcuate 2 region and 1 point in the region adjacent to the blind spot in the superior hemifield had significantly worse TD values than their inferior counterparts (Figure 3-E). In NTG eyes, 1 point of the central region and several points clustering in the nasal, arcuate 1 and arcuate 2 regions had significantly worse TDs than their inferior-hemifield counterparts (Fig. 3-F).

When the comparisons were conducted using PD values, the superior hemifield was also affected more severely than the inferior hemifield (Figure S1 and S2).

**Relationship Between PSD and mean TD**

The relationship between PSD and mean TD in the three groups followed an inverted-U shape, demonstrating that PSD worsens as mean TD worsens until the damage is so extensive that the PSD begins to decline again. (Figure 4) The best-fit quadratic curves for the NTG, HTG, and PACG groups demonstrated that the NTG group had greater PSD values and the PACG group had lower PSD values for a given mean TD. After controlling for mean TD and (mean TD)$^2$, the PACG group had significantly lower PSD values for a given mean TD than either the NTG or HTG group (all P <0.001).

**Discussion**

In early stage PACG eyes in the current study, the nasal region in the superior hemifield had significantly worse VF damage than in the inferior counterpart region. These results are consistent with reports by Bonomi et al.\textsuperscript{37} based on 53 eyes with acute angle-closure glaucoma attacks and Lau et al.\textsuperscript{38} in early stage PACG eyes. On the other hand, Gazzard et al.\textsuperscript{27} found that the central region of advanced stage PACG eyes had significantly greater damage in the superior compared to the inferior hemifield. Atalay et al.\textsuperscript{35} reported that five regions in the superior hemifield had significantly worse MDs compared with their inferior counterparts in advanced PACG eyes. Yousefi et al.\textsuperscript{36} also observed more severe damage in the central and peripheral (arcuate 2) regions of advanced PACG eyes. These three studies are in agreement with our finding that the central region in advanced PACG eyes has significantly worse VF damage in the superior than in the inferior hemifield.

In HTG eyes in the current study, the central region in the early stage, and the central and paracentral regions in the advanced stage had significantly greater damage in the superior compared to the inferior hemifield. This is similar to the report from Gazzard and associates.\textsuperscript{27} who compared the characteristics of VF defect between HTG and PACG eyes. Their early HTG eyes had significantly lower mean pattern deviation in the paracentral region of the superior hemifield than in the inferior hemifield; advanced HTG eyes had significantly lower mean pattern deviation in the superior central region. In the early and advanced HTG eyes in both Gazzard et al.\textsuperscript{27} and the current study, only the central and paracentral region in the superior hemifield was more damaged than the corresponding inferior region. Whereas, in a previous study conducted by Yousefi et al.\textsuperscript{36}, almost all superior GHT regions had significantly worse VF damage than the corresponding inferior regions in Japanese POAG patients. The main reason for this disagreement in the asymmetric VF defect patterns among these studies is likely the different criteria used in defining POAG. In the Yousefi\textsuperscript{36} study, POAG was defined as the presence of glaucomatous optic neuropathy with open anterior
chamber angle, while IOP was not a diagnostic criterion. The proportion of NTG among POAG cases in the Japanese population is as high as 92%,\textsuperscript{39} and thus a number of NTG cases may be included in the POAG group in the Yousefi study, which may have influenced the VF defect patterns in POAG eyes.

In NTG eyes, five regions at the early stage and three regions at the moderate stage had significantly greater damage in the superior compared to the inferior hemifield. Park et al\textsuperscript{40} evaluated the patterns of VF defects in 34 NTG eyes by dividing probability plots into 2 subfields in each of the hemifields. They found that the depth of VF defects in the superior paracentral area was greater than in the corresponding inferior area, which is consistent with our study. As described above, Yousefi et al\textsuperscript{36} assessed VF damage among Japanese patients with POAG, among whom many cases were likely NTG. They observed that three GHT regions in the early stage, and five GHT regions in the moderate and advanced stages had significantly worse VF damage than the corresponding inferior regions. This is in agreement with our findings, to a certain extent. Huang et al\textsuperscript{29} compared VF loss in NTG, POAG, and PACG patients, however, their comparison mainly focused on interocular asymmetry.

In the current study, PACG patients were more likely to be female than patients with HTG. This is consistent with previous studies suggesting that women are at greater risk of PACG than men.\textsuperscript{41-43} PACG patients were significantly older than HTG patients, also consistent with previous population-based studies suggesting that older age is a strong risk factor for PACG.\textsuperscript{42,44-46} Patients with NTG in this study were recruited from a community screening for subjects aged 50 years or older.\textsuperscript{31} This may partly explain the finding that NTG patients were significantly older than HTG patients. A more hyperopic SE refraction was observed in PACG than in NTG and HTG, which is in agreement with previous reports describing the strong association between hyperopia and PACG, whereas myopia is reported to be associated with POAG.\textsuperscript{36,47,48} Patients with NTG recruited from community screening had significantly better VF parameters, and were more likely to be in the early or moderate stages of glaucoma than patients with HTG and NTG. This finding is in accord with prior reports, including our own on this screening cohort, that glaucoma patients detected by screening had significantly milder VF damage than those diagnosed initially in clinic.\textsuperscript{31,49}

The MD of regions in the superior hemifield were worse than their inferior counterpart regions in the 3 subtypes of primary glaucoma; this result is in accordance with previously studies. Caprioli et al\textsuperscript{19} evaluated the VF of patients with NTG and HTG by computerized perimetry (Octopus programs, 30-degree visual field) and found that the densest scotomas occurred more commonly in the superior hemifield in both groups. Heijl et al\textsuperscript{50} evaluated the distribution of VF loss in HTG patients using automated perimetry and found VF loss to be more common superiorly than inferiorly. McNaught et al\textsuperscript{51} also reported similar asymmetric VF damage in patients with PACG. This tendency towards vertically asymmetric VF defects has also been demonstrated in studies using static automated perimetry.\textsuperscript{27,35,36} Retinal ganglion cells axons converge at the optic nerve head, travel through the lamina cribrosa, and enter the optic nerve.\textsuperscript{52} The structural changes of the optic nerve head and lamina cribrosa result in a corresponding functional loss of VF, and eyes with lamina cribrosa defects in the inferior half of the optic nerve head have worse VF loss in the superior hemifield.\textsuperscript{53} Asymmetry of VF defects is likely related to the pattern of susceptibility of the optic nerve head. Previous studies have demonstrated that the inferior temporal ONH has lower collagen density compared to other regions,\textsuperscript{54} rendering it more susceptible to damage during the onset and progression of glaucoma. Consistent with vitro studies, the infero-temporal region of the optic nerve head has greater susceptibility to glaucomatous damage than other areas: Caprioli et al\textsuperscript{15} found that patients with POAG had greater thinning of the neuroretinal rim in the inferior and inferotemporal regions. Nouri-Mahdavi et al\textsuperscript{26} also reported a higher prevalence of localized rim loss in the inferotemporal sector of the optic disc in patients with POAG and PACG. Such structural differences likely underlie the greater vulnerability of the superior VF to glaucomatous damage.

The different patterns of superior-inferior asymmetry in VF defects in the 3 glaucoma subtypes may be associated with their different pathogenic mechanisms. PACG is principally an IOP-dependent glaucoma, due to elevated IOP secondary to angle closure.\textsuperscript{4} The mechanism of HTG is thought to be mixed, but with visual field damage most closely linked to the level of IOP.\textsuperscript{55} IOP-independent mechanism including vasogenic risk factors are likely to play a more significant role in the pathogenesis of glaucomatous optic neuropathy in NTG, compared to HTG.\textsuperscript{6,8,9} Mechanisms of visual field damage caused by IOP-dependent factors may differ from those caused by IOP-independent factors, and this may underlie the observed differences in the patterns of VF defects between NTG, PACG or HTG patients in the current and other studies. Furthermore, studies of the
morphologic characteristics of the optic nerve head have also found difference between the 3 subtypes glaucoma: NTG eyes have a larger cup and smaller rim than those with HTG\textsuperscript{14,15,56,57} and PACG\textsuperscript{16}. These different patterns of glaucomatous optic neuropathy may be a further indication of different pathogenic mechanisms of glaucoma damage in patients with PACG, HTG and NTG.

In the current study, PACG eyes had a lower PSD than those with NTG and HTG. This finding agrees with previous studies reporting that VF loss in PACG eyes is more diffuse than in POAG eyes at the same level of overall field damage\textsuperscript{26-28,36}. NTG eyes in the current study had higher PSD than those with HTG for a given mean TD, which is consistent with previous reports that POAG with lower IOP tends to have more localized field defects compared to cases with higher pressure\textsuperscript{20}.

Strengths of our study include the fact that it is one of the first to compare the patterns of VF defects between patients with PACG and POAG in China. Over the last two decades, data on this important topic from China are limited to only a few small studies\textsuperscript{27,29,35}, only one of which included patients with NTG, focusing only on inter-ocular asymmetry and including few patients (42 NTG, 38 POAG, and 37 CACG).\textsuperscript{29} NTG patients in the current report were recruited from a longitudinal, community-based study, which may strengthen the generalizability of findings.

Limitations of this study must also be acknowledged. Firstly, the HTG and PACG patients were recruited from clinical settings, which tended to include more severely-affected patients compared to the NTG patients identified in the community. Secondly, although we excluded patients with vision impairment or blindness, prevalent cataract may still have affected the pattern of observed VF defects. Finally, the study was cross-sectional, while a longitudinal design would be needed to determine the pattern of progression in the different sub-types of primary glaucoma.

In summary, we found that the superior hemifield is affected more severely than the inferior hemifield in all three subtypes of primary glaucoma, and this tendency is more pronounced in NTG compared to PACG and HTG. Moreover, the VF damage in NTG and HTG is more localized than that in PACG.

Declarations

Acknowledgments

None.

Authors contributions

Involved in Design of study (L.Y.B, L.F, J.J.H); conduct of study (J.J.H, Y.C, Z.C, Y.W.C); data collection (W.X.Y, S.X, X.X, Z.H.T, Z.J.W); analysis and interpretation of data (Z.C, Z.S.D, Z.J.J, H.J.J); statistical expertise (J.J.H, Z.C); writing the article (J.J.H, C.N); and critical revision of the article (L.Y.B, L.F).

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**Tables**
Table 1. Demographic Characteristics of Participants (Data represent mean +/- standard deviation (SD) except where indicated).

| Subtypes | Characteristics      | Total | Early | Moderate | Advanced | P     |
|----------|----------------------|-------|-------|----------|----------|-------|
|          | Eyes, n              | 162   | 57    | 31       | 74       |       |
| PACG     | Age (year)           | 62.6±9.3 | 60.9±10.5 | 64.3±8.1 | 63.3±8.7 | 0.501 |
|          | Male Gender, n (%)   | 51(44.7%) | 18(41.9%) | 9(39.1%) | 24(50.0%) | 0.275 |
|          | VA (logMAR)          | 0.16±0.16 | 0.12±0.14 | 0.11±0.14 | 0.21±0.16 | 0.001 |
|          | SE (D)               | 0.16±1.49 | -0.01±1.90 | 0.58±1.11 | 0.11±1.24 | 0.127 |
|          | IOP (mmHg)           | 16.63±7.90 | 14.68±6.31 | 16.37±5.52 | 18.25±9.43 | 0.039 |
|          | TD (dB)              | -14.21±10.58 | -3.46±1.96 | -9.14±1.70 | -24.61±5.65 | < 0.001 |
|          | MD (dB)              | -13.88±10.77 | -3.10±1.81 | -8.51±1.69 | -24.44±6.00 | < 0.001 |
|          | PSD (dB)             | 6.13±3.50 | 3.12±1.54 | 7.74±2.74 | 7.76±3.35 | < 0.001 |
|          | VFI (%)              | 61.57±35.13 | 95.14±3.07 | 80.87±7.07 | 27.62±22.09 | < 0.001 |
|          |                      |       |       |          |          |       |
| HTG      | Eyes, n              | 111   | 24    | 16       | 71       |       |
|          | Age (year)           | 54.7±15.6 | 47.6±18.0 | 63.2±15.1 | 55.4±13.4 | 0.002 |
|          | Male gender, n (%)   | 50(67.6%) | 14(73.7%) | 7(58.3%) | 29(67.4%) | 0.102 |
|          | VA (logMAR)          | 0.20±0.15 | 0.14±0.16 | 0.19±0.17 | 0.22±0.14 | 0.126 |
|          | SE (D)               | -1.36±2.36 | -1.63±2.78 | -1.36±2.90 | -1.27±2.10 | 0.840 |
|          | IOP (mmHg)           | 18.70±8.14 | 18.34±5.07 | 16.68±4.62 | 19.27±9.48 | 0.195 |
|          | TD (dB)              | -16.72±9.93 | -2.71±2.35 | -9.34±2.10 | -23.13±5.55 | < 0.001 |
|          | MD (dB)              | -16.79±10.17 | -2.62±2.33 | -9.12±1.93 | -23.31±5.88 | < 0.001 |
|          | PSD (dB)             | 8.01±3.99 | 3.94±2.51 | 8.93±4.47 | 9.18±3.38 | < 0.001 |
|          | VFI (%)              | 50.68±32.78 | 94.08±5.59 | 77.63±9.23 | 29.94±20.30 | < 0.001 |
|          |                      |       |       |          |          |       |
| NTG      | Eyes, n              | 148   | 92    | 36       | 20       |       |
|          | Age (year)           | 62.8±13.1 | 63.1±11.9 | 65.4±11.7 | 56.8±19.2 | 0.185 |
|          | Male gender, n (%)   | 49(48.0%) | 34(51.5%) | 8(34.8%) | 7(53.9%) | 0.935 |
|          | VA (logMAR)          | 0.20±0.15 | 0.19±0.14 | 0.19±0.16 | 0.25±0.15 | 0.255 |
|          | SE (D)               | -1.36±3.00 | -1.05±2.81 | -1.36±3.25 | -2.76±3.15 | 0.157 |
|          | IOP (mmHg)           | 14.38±3.50 | 14.66±3.56 | 14.18±3.27 | 13.44±3.59 | 0.443 |
|          | TD (dB)              | -6.34±5.17 | -3.24±2.04 | -8.60±1.53 | -16.51±4.22 | < 0.001 |
|          | MD (dB)              | -6.17±5.28 | -3.00±1.94 | -8.42±1.58 | -16.72±4.21 | < 0.001 |
|          | PSD (dB)             | 6.60±3.98 | 4.41±2.39 | 8.98±3.30 | 12.40±2.39 | < 0.001 |
|          | VFI (%)              | 83.75±15.61 | 92.68±4.92 | 77.97±6.86 | 53.05±15.53 | < 0.001 |

VA = visual acuity; SE = spherical equivalent; IOP = intraocular pressure; TD = total deviation; MD = mean deviation; PSD = pattern standard deviation; VFI = visual field index. Data are mean ± standard deviation unless otherwise indicated.
| Variable                      | PACG       | HTG       | NTG       | P       |
|-------------------------------|------------|-----------|-----------|---------|
| Eyes, n                       | 48         | 48        | 48        |         |
| Age (year)                    | 61.2 (7.98)| 56.1 (17.3)| 58.8 (15.9)| 0.154  |
| Male Sex, n (%)               | 16 (38.1%) | 25 (61.0%)| 20 (46.5%)| 0.310  |
| MD (dB)                       | -7.40 (5.99)| -9.76 (8.74)| -8.04 (7.26)| 0.272  |
| VF defects severity, n (%)    |            |           |           | 0.644  |
| Early stage                   | 24(50.0%)  | 21(43.8%) | 24(50.0%)|         |
| Moderate stage                | 15(31.2%)  | 14(29.2%) | 12(25.0%)|         |
| Advanced stage                | 9(18.8%)   | 13(27.1%) | 12(25.0%)|         |

MD = mean deviation; VF = visual field. Data are mean ± standard deviation unless otherwise indicated.
| Glaucoma | Region       | Subregion | Mean TD  | P     | Mean TD  | P     | Mean TD  | P     |
|----------|--------------|-----------|----------|-------|----------|-------|----------|-------|
| PACG     | Central      | Superior  | -2.84±3.13 | 0.850 | -7.63±7.33 | 0.376 | -23.28±9.45 | <0.001 |
|          |              | Inferior  | -2.92±3.77 |       | -6.02±6.60 |       | -19.10±9.47 |       |
|          | Paracentral  | Superior  | -2.97±2.31 | 0.276 | -10.44±8.39 | 0.145 | -25.83±8.12 | 0.187 |
|          |              | Inferior  | -2.63±2.16 |       | -7.13±4.37 |       | -24.43±8.98 |       |
| Nasal    | Superior     | -4.60±4.30 | 0.032 |       | -14.03±7.53 | 0.177 | -27.12±6.11 | 0.579 |
|          | Inferior     | -3.485±2.56 |       |       | -11.04±6.82 |       | -26.71±6.94 |       |
|          | Peripheral, arcuate 1 | Superior | -3.72±3.32 | 0.394 | -10.23±5.62 | 0.087 | -25.95±5.62 | 0.856 |
|          |              | Inferior  | -3.392±2.80 |       | -7.76±4.49 |       | -25.79±8.00 |       |
|          | Peripheral, arcuate 2 | Superior | -3.65±4.15 | 0.339 | -9.38±6.90 | 0.259 | -24.75±6.38 | 0.640 |
|          |              | Inferior  | -3.15±2.61 |       | -7.69±5.33 |       | -25.23±7.91 |       |
| Hemield  | Superior     | -3.65±2.72 | 0.305 |       | -10.62±4.67 | 0.150 | -25.61±6.18 | 0.247 |
|          | Inferior     | -3.17±2.12 |       |       | -8.14±3.80 |       | -24.74±6.91 |       |
| HTG      | Central      | Superior  | -3.51±5.83 | 0.022 | -10.19±9.77 | 0.767 | -23.83±8.55 | 0.015 |
|          |              | Inferior  | -1.35±2.12 |       | -8.98±9.60 |       | -20.22±10.56 |       |
| Paracentral | Superior  | -3.21±3.99 | 0.394 |       | -8.66±8.46 | 0.775 | -27.12±7.69 | 0.045 |
|          |              | Inferior  | -2.63±2.93 |       | -9.73±8.80 |       | -24.53±9.46 |       |
| Nasal    | Superior     | -4.29±6.33 | 0.050 |       | -13.56±9.16 | 0.664 | -25.20±6.87 | 0.253 |
|          | Inferior     | -1.88±3.13 |       |       | -12.00±7.43 |       | -23.88±8.53 |       |
|          | Peripheral, arcuate 1 | Superior | -2.54±3.34 | 0.792 | -7.80±6.57 | 0.643 | -24.12±7.98 | 0.647 |
|          |              | Inferior  | -2.36±3.13 |       | -9.19±7.41 |       | -23.48±9.17 |       |
|          | Peripheral, arcuate 2 | Superior | -3.08±5.13 | 0.814 | -6.91±7.11 | 0.604 | -23.21±7.90 | 0.397 |
|          |              | Inferior  | -2.82±3.56 |       | -8.09±6.54 |       | -22.00±10.23 |       |
| Hemield  | Superior     | -3.29±3.98 | 0.214 |       | -9.43±6.46 | 0.915 | -24.71±6.23 | 0.112 |
|          | Inferior     | -2.24±2.57 |       |       | -9.70±6.38 |       | -23.05±8.33 |       |
| NTG      | Central      | Superior  | -2.76±4.02 | 0.039 | -10.87±9.32 | 0.008 | -14.38±10.43 | 0.646 |
|          |              | Inferior  | -1.83±2.95 |       | -5.22±4.36 |       | -16.03±11.56 |       |
|          | Paracentral  | Superior  | -4.15±4.89 | <0.001 | -10.70±8.92 | 0.165 | -16.80±12.55 | 0.666 |
|          |              | Inferior  | -2.27±3.27 |       | -7.34±7.55 |       | -18.73±11.37 |       |
|                | Superior       | Inferior       | Superior       | Inferior       | Superior       | Inferior       |
|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Nasal          | -5.32±5.46     | -3.77±5.46     | -12.87±9.20    | -7.84±7.95     | -20.18±10.71   | -21.83±9.63    |
| Peripheral, arcuate 1 | Superior     | -4.89±4.49     | -10.07±6.54    | -6.71±6.37     | -17.33±12.39   | -18.28±9.30    |
| Peripheral, arcuate 2 | Superior     | -4.74±5.72     | -9.84±7.36     | -6.31±7.22     | -14.68±11.98   | -13.41±10.03   |
| Hemifield      | -4.54±3.63     | -1.13±1.99     | -10.89±5.85    | -6.80±5.34     | -17.00±10.47   | -17.98±7.29    |

Data represent mean ± standard deviation.