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Topographic correlation between optic nerve head characteristics and retinal nerve fibre layer defect in primary open-angle glaucoma patients: Korea National Health and Nutrition Examination Survey

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ABSTRACT.

Purpose: **To evaluate topographic correlations of the directions of β-zone peripapillary atrophy (PPA) and optic disc torsion with retinal nerve fibre layer (RNFL) defect in a Korean population.**

Methods: **Among 292 primary open-angle glaucoma (POAG) patients from the 2012 KNHANES (n = 7444, age ≥ 19 years), 93 eyes of 93 individuals with a single localized RNFL defect were enrolled. The angular locations of the point of maximum radial extent (PMRE) of β-zone PPA and the optic disc torsion were measured on fundus photography. The angular location of the PMRE and the torsion degree (TD) were noted when the absolute value of the former or the latter was ≥15 degrees from the reference line, a line drawn from the centre of the optic disc to the fovea.**

Results: **The overall POAG prevalence was estimated as 4.2% (95% confidence interval [CI], 3.6–4.9). Of the POAG eyes with a single localized RNFL defect, 39.5% had superior or inferior PMRE of β-zone PPA; in 74.9% (p = 0.015) of those cases, the RNFL defect was located in the same hemifield as the angular location of the PMRE. Meanwhile, 40.4% of the POAG eyes with a single localized RNFL defect showed accompanying optic disc torsion. The correlation rate between the direction of the optic disc torsion and the RNFL defect location was 60.2% (p = 0.029).**

Conclusions: **In the Korean POAG patients examined, the directions of the PMRE of β-zone PPA and of the optic disc torsion showed significant associations with the RNFL defect location.**

Key words: primary open-angle glaucoma – peripapillary atrophy – optic disc torsion – retinal nerve fiber layer defect – Korea National Health and Nutrition Examination Survey

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Introduction

Glaucoma has been reported as the leading cause of irreversible visual loss globally. The World Health Organization (WHO)'s 2002 estimate of the number of people suffering blindness from glaucoma was 4.4 million (12.3% of blind people worldwide) (Resnikoff et al. 2004). Primary open-angle glaucoma (POAG) is the most commonly reported type in Korea, with rates ranging from 2.0 to 3.5%, and with a majority of cases showing low intraocular pressure (IOP) at diagnosis (Kim et al. 2011; Yoon et al. 2011). As early primary open-angle glaucoma is in most cases asymptomatic, diagnosis often comes late, after irreversible optic nerve damage has been incurred. Preservation of vision is best achieved by early diagnosis, which is to say, prior to perception of abnormality by the patient.

Loss of optic nerve axons can be represented by ophthalmoscopically visible defects in the retinal nerve fibre layer (RNFL). Because such RNFL changes typically precede the appearance of functional changes in the visual field, they are of potentially great value as early indicators of disease (Quigley

et al. 1992). Recently, the topographic correlation between optic nerve head (ONH) parameters and RNFL defect has been investigated. Specifically, β-zone peripapillary atrophy (PPA) and optic disc torsion have been shown to be spatially associated with RNFL defect (Park et al. 2012; Cho & Park 2013; Lee et al. 2014a,b). These studies, however, were referral clinic based, and so their subjects were unrepresentative of the general Korean population. Population-based evaluation of the significance of the topographic correlation between ONH parameters and RNFL defect in Korean POAG patients, then, has remained a necessity.

The primary aim of this study was to investigate the topographic correlation between ONH parameters (i.e. β-zone PPA and optic disc torsion) and the hemispheric location of RNFL defect for Korean POAG patients selected from a population-based survey.

Methods

Study population

The Korea National Health and Nutrition Examination Survey (KNHANES) is a nationwide population-based cross-sectional survey involving a representative civilian non-institutionalized South Korean population. Initiated in 1998, the survey has been conducted annually since 2007 by the Korea Center for Disease Control and Prevention (KCDC) (Yoon et al. 2011). Ophthalmologic examinations have been included in the survey since the latter half of 2008. This study was based on data collected during the final year of KNHANES V (KNHANES V-3, 2012).

In KNHANES V, to prevent omission or overlap, 3840 households across 192 national enumerated districts were selected annually using a stratified multistage cluster sampling design based on the National Census Data. The enumerated districts were geographic areas representing a specific portion of a city or a county, from which 20 households were selected using systematic sampling (Yoon et al. 2011). All family members of selected households aged 1 year and above were included as eligible subjects. They were asked to participate in both the Health Interview Survey and the Health Examination Survey, the latter including ophthalmologic examinations. All of the examinations and interviews were carried out by trained teams in mobile centres. Ultimately, 5612 participants aged 19 years or older who had 1 or more evaluable fundus photograph were included in this study. Among them, eyes diagnosed as POAG with a single RNFL defect were examined. In cases where both eyes met the inclusion criteria, the left eye was chosen randomly. The tenets of the Declaration of Helsinki were adhered to. Written informed consent had been obtained from all of the subjects for their inclusion in KNHANES V. The Institutional Review Board (IRB) of Seoul National University Hospital determined that their approval was not required for the purposes of this study, as all KNHANES data are made publicly available after removal of personal identifiers and anonymization.

Ocular examinations

Participants received complete ocular examinations performed by trained ophthalmologists. Uncorrected visual acuity (UCVA) and/or best-corrected visual acuity (BCVA) were measured on the LogMar Scale using an international standard vision chart (Jin's Vision Chart, Seoul, Korea) at a distance of 4 m; autorefraction was performed using an autorefractor/keratometer (KR8800; Topcon, Tokyo, Japan); slit-lamp examination, including assessment of peripheral anterior chamber depth (PACD), by the Van Herick method (Haag-Streit model BQ-900; Haag-Streit AG, Koeniz, Switzerland), and fundus photography, by digital non-mydriatic fundus camera (TRC-NW6S; Topcon/Nikon D-80 digital camera; Nikon, Tokyo, Japan). The spherical equivalent (SE) refractive error was calculated as the spherical power plus half of the cylindrical power, measured in dioptres (D). IOP was measured once per eye by trained ophthalmologists using a Goldmann applanation tonometer (GAT; Haag-Streit; Haag-Streit AG, Koeniz, Switzerland) during the slit-lamp examination, prior to the perimetry and fundus photography. If the participants had elevated IOP >21 mmHg or a glaucomatous optic disc (criteria: (1) horizontal or vertical cup-to-disc ratio (VCDR) equal to or >0.5, (2) non-adherence to the ISNT rule [i.e. neuroretinal rim thickness in the following order by quadrant: inferior >superior >nasal >temporal], (3) presence of optic disc haemorrhage, or (4) presence of RNFL defect), frequency-doubling perimetry testing (FDT; Humphrey Matrix; Carl Zeiss Meditec Inc., Dublin, CA, USA) with the N-30-1 screening program was carried out. If there were 2 or more fixation errors, false positives or negatives, a verbal explanation was provided and the FDT test was repeated. If both tests were determined to be unreliable, the subject was considered to have unreliable visual-field test data.

Definition of glaucoma

Participants' glaucoma was defined based on either of the two modified criteria of the International Society of Geographical and Epidemiological Ophthalmology (ISGEO) (Foster et al. 2002). Category 1 requires both structural damage and the presence of abnormal FDT testing results as well as fixation error and false-positive error equal to or <1: either VCDR equal to or >0.7 (97.5th percentile) or asymmetry of VCDR equal to or >0.2 (97.5th percentile), or the presence of optic disc haemorrhage or RNFL defect, plus the presence of an abnormal FDT testing result (at least one location of reduced sensitivity). Category 2 requires advanced structural damage with unproved visual-field loss (absence of FDT testing results or number of fixation errors or false-positive errors equal to or >2): VCDR equal to or >0.9 (99.5th percentile) or asymmetry of VCDR equal to or >0.3 (99.5th percentile). POAG was defined as glaucoma with the presence of an open angle as determined by the Van Herick method (PACD greater than 1/4 corneal thickness).

Identification of localized RNFL defect locations

Localized RNFL defect was defined on digital fundus photography as a well-outlined, dark, wedge-shaped area within the bright striated pattern of the surrounding healthy nerve fibre layer. The tip of the dark area needed to touch the optic disc border, and the shape of the dark area could not show either a linear or a fusiform shape. The

hemispheric RNFL defect locations were documented by qualified ophthalmologic researchers using a combination of paper and digital formats. Concordance between the qualified researchers and glaucoma subspecialists was evaluated later by comparing their respective interpretations of the RNFL defect locations. According to those locations, the eyes were further categorized into superior and inferior defect groups. Defects in both the superior and inferior hemifields were excluded from the analysis. Eyes with poor-quality fundus photographs (with which β-zone PPA or RNFL defect identification was difficult) also were excluded. In an effort to minimize misdiagnosis, we combined the functional (FDT) and structural (fundus photography) findings for open-angle glaucoma and also excluded participants with retinal disease [e.g. age-related macular degeneration (AMD), branch retinal vein occlusion (BRVO)] or congenital optic nerve anomaly [e.g. superior segmental optic hypoplasia (SSOH)] that could lead to non-glaucomatous VF defects. Patients were diagnosed as AMD if they had any hard or soft distinct drusen, retinal pigment epithelium (RPE) abnormalities, geographic atrophy, RPE detachment, serous detachment of the neurosensory retina, subretinal or sub-RPE haemorrhages, or subretinal fibrous scarring (Bird et al. 1995; Cho et al. 2014). Patients were defined as BRVO with either a wedge-shaped distribution of intraretinal haemorrhage and/or occluded and sheathed retinal veins on fundus photograph (Klein et al. 2000). SSOH was defined as rim thinning of the optic nerve head in the superior or superonasal region with corresponding RNFL defect (Yamamoto et al. 2004; Seo et al. 2014).

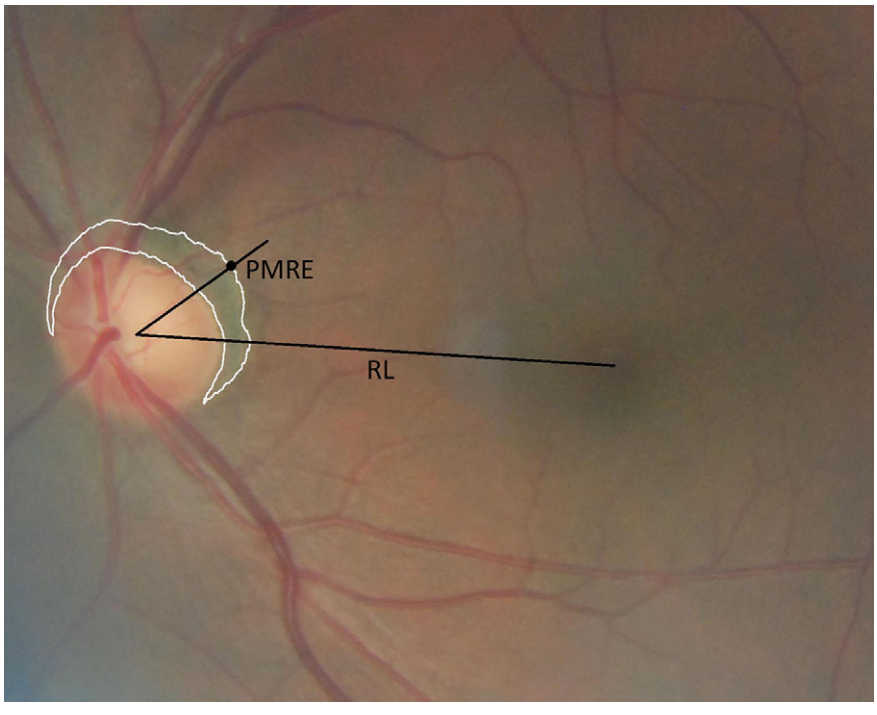

Fig. 1. Topographic measurement of β-zone parapapillary atrophy (PPA). Using a mouse-driven cursor, a new contour line was drawn around the β-zone PPA to trace the disc and PPA margins. The reference line (RL) was manually drawn from the centre of the disc to the centre of the fovea. The point of maximum radial extent (PMRE) was the point on the temporal β-zone PPA margin at which the radial extent of β-zone PPA was maximal. The angular location of PMRE was determined by measuring the angle between the RL and a line from the centre of the disc to the PMRE.

Discrimination and topographic measurement of β-zone PPA

Two masked glaucoma specialists independently evaluated the optic disc on fundus photography; discrepancies between them were resolved by consensus agreement. These assessments were performed without knowledge of the corresponding clinical information.

All of the subjects' fundus photographs were reviewed to identify eyes with β-zone PPA. β-zone PPA was defined as an inner crescent of chorioretinal atrophy with visible sclera and choroidal vessels adjacent to the optic disc (Jonas & Naumann 1989; Jonas et al. 1989; Jonas 2005). The β-zone PPA parameters were measured on optic disc photographs using the method described by Cho & Park (2013). To evaluate the PPA area, a new contour line was drawn to delineate it, using a mouse-driven cursor to trace the disc and PPA margins directly onto the image using Image J software (version 1.45s; developed by Wayne Rasband, National Institutes of Health, Bethesda, MD; available at: http://rsb.info.nih.gov/ij/index.html).

A reference line (RL) was then drawn from the centre of the optic disc to the centre of the macula. The centre of the macula was defined as a punctate central reflex of the band-like reflex on fundus photography, which was reviewed on an LCD monitor. The centre of the optic disc was determined considering the longest and the shortest diameter, and the contour of optic disc, using image J software. The point of maximum radial extent (PMRE) of β-zone PPA on the temporal β-zone PPA margin was identified as described in our previous study (Cho & Park 2013). The angular location of the PMRE on fundus photography, defined as the angle between the reference line and a line from the centre of the disc to the PMRE (Fig. 1), was measured with a mouse-driven cursor using Image J software. If the midpoint or PMRE was superior to the reference line, the location angle was designated as positive; if the midpoint was located inferiorly, the location angle was designated as negative. Absolute values of the angular location of PMRE equal to or >15 degrees were included in the study. The investigators were masked to the clinical status of each patient. However, for technical reasons, masking of the intrapapillary region and RNFL defect was not possible. The reproducibility in terms of interobserver agreement of angular location of PMRE was excellent (intraclass correlation coefficient = 0.967, 95% CI = 0.939–0.983, $p < 0.001$).

Measurement of optic disc tilt and torsion

Optic disc torsion was measured on fundus photography by two glaucoma

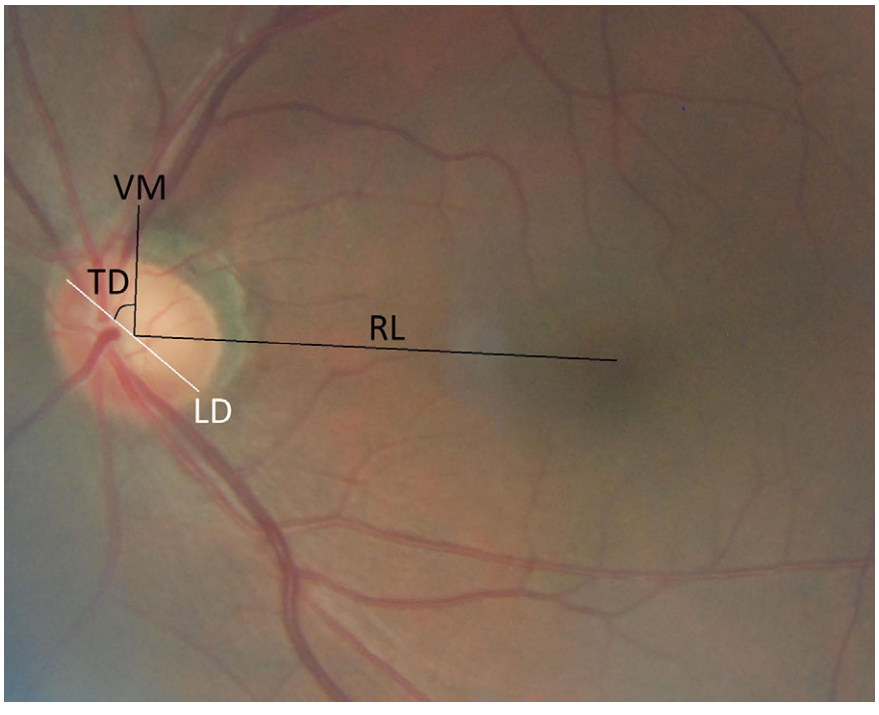

Fig. 2. Identification of torsion degree on fundus photography. The vertical meridian (VM) was identified as a line extending perpendicularly from the reference line (RL). The angle between the long axis of the optic disc (LD) and the VM of the optic disc was deemed the torsion degree (TD).

specialists using Image J software. The definitions of optic disc torsion are available in the literature (Vongphanit et al. 2002; How et al. 2009; Park et al. 2012; Lee et al. 2014,a,b). Briefly, optic disc torsion is defined as the deviation of the long axis of the optic disc from the vertical meridian; the vertical meridian is identified as the line extending perpendicularly from the reference line. The angle between the vertical meridian and the long axis of the optic disc is deemed the torsion degree (Fig. 2). When the absolute value of the torsion degree (TD) was more than 15 degrees, the optic disc in question was classified as a torsioned disc. A positive torsion value indicated superior torsion, and a negative value indicated inferior torsion.

Statistical analysis

Statistical estimates were derived using sample weights adjusted for response rate, extraction rate and the distribution of the Korean population in 2012. This was carried out to reflect the complex sampling design and sampling weights of KNHANES and also to provide representative national prevalence estimates. Continuous variables were expressed as adjusted mean ± standard errors or mean values with the 95% confidence interval (CI). The superior and inferior defect groups' data were subjected to univariate logistic regression analysis to screen for potential variables of RNFL defect location. The demographic and ocular parameters included in the analysis were age, gender, IOP, refractive error and direction of RNFL defect. Risk factors with $p < 0.1$ were selected, adjusting for potential confounders. Subsequently, a multivariate logistic regression analysis was performed using a stepwise selection method. Using the set of '$p < 0.05$' risk factors selected in this analysis, final RNFL defect location models were constructed. Then, to evaluate the correlation with RNFL defect location (by Pearson's chi-square test), the study population was further divided into a β-zone PPA group (≥15° absolute value of angular location of PMRE) and an optic disc torsion group (≥15° absolute value of torsion). The potential confounding variables distributed across participants were compared using a design-adjusted Rao–Scott Pearson-type chi-square and two sample t-tests for categorical and continuous variables, respectively. Statistical analyses were performed using IBM SPSS for Windows software, version 18.0 (IBM Corp., Armonk, NY, USA) and the SAS survey procedure (version 9.4; SAS Institute, Inc., Cary, NC, USA). For all of the analyses, p values <0.05 were considered to indicate statistical significance.

Table 1. POAG patients' RNFL defect locations.

RNFL defect	Number of subjects	Incidence (%)*	95% CI*
Superior	57	24.2	18.3–31.2
Inferior	36	10.3	6.7–15.4
Both	38	11.2	7.3–16.7
No RNFL defect	149	54.3	46.4–62.0

* Weight-adjusted estimation of percentage in each group.

Table 2. Clinical characteristics of POAG patients by location of RNFL defect.

	Superotemporal defect	Inferotemporal defect	p Value
Age (years)‡	57.58 ± 2.31	59.97 ± 1.84	0.420*
Gender (female, %)§	33.0	347.0	0.246†
Intra-ocular pressure (mmHg)‡	13.19 ± 0.67	15.15 ± 0.65	0.065*
Spherical equivalent (D)‡	−0.68 ± 0.29	−0.72 ± 0.33	0.942*
β-zone PPA-to-disc area ratio‡	0.23 ± 0.04	0.46 ± 0.25	0.345*
Location angle of PMRE (°)‡	0.47 ± 3.76	−22.74 ± 8.45	0.008*
Torsion degree (°)‡	−1.39 ± 3.01	−24.64 ± 6.79	0.001*

PPA, peripapillary atrophy; PMRE, point of maximum radial extent.
* Independent *t*-test for complex samples.
† Chi-square test for complex samples.
‡ Weight-adjusted estimation of numerical values are shown as mean ± standard error.
§ Weight-adjusted estimation of percentage in each group.

Results

From January to December 2012, 5612 individuals aged 19 years or older underwent fundus photography. Their mean age was 51.55 ± 2.37 years. The male gender accounted for 45.63 ± 0.67% of the participants. The mean refractive error was −1.01 ± 0.06 dioptres, and the mean IOP was 13.86 ± 0.16 mmHg. POAG was diagnosed in 292 of the 5612 subjects, for an overall prevalence rate of 4.2% (95% CI: 3.6–4.9). Among those, 57.8% (95% CI: 49.2–65.9) had β-zone PPA, 13.6% (95% CI: 9.5–19.2) had β-zone PPA with angular location of PMRE equal to or >15 degrees, while 36.5% (95% CI: 29.7–43.8) had optic disc torsion. Of those 292 eyes diagnosed as POAG, 93 eyes of 93 individuals with a single RNFL defect were enrolled. Among them, 24.2% (95% CI: 18.3–31.2) had superior RNFL defects, while 10.3% (95% CI: 6.7–15.4) had inferior RNFL defects (Table 1).

The characteristics of the POAG eyes with single RNFL defects are listed in Table 2. The superior defect group showed, relative to the inferior defect group, no significant differences in baseline characteristics, age, gender, IOP, SE or β-zone PPA-to-disc area ratio. The mean (± standard error) location angle of PMRE and torsion degree, however, significantly differed between the groups (p = 0.008 versus p = 0.001, Independent *t*-test for complex samples).

The location of the PMRE and the torsion direction were significantly associated with the direction of RNFL defect in both the univariate (p = 0.015 and 0.007) and the multivariate (p = 0.004 and 0.019) logistic regression analyses (Table 3).

Of the POAG eyes with a single localized RNFL defect, 39.5% (95% CI: 28.4–51.8) had β-zone PPA with angular location of PMRE equal to or >15 degrees; in 74.9% (p = 0.015, Pearson's chi-square test for complex samples) of those cases, the RNFL defect was located in the same hemifield as the angular location of the PMRE (Table 4). Also, 40.4% of the POAG eyes with a single localized RNFL defect were accompanied by optic disc torsion. The correlation rate between the RNFL defect location and the direction of the optic disc torsion was 60.2% (p = 0.029; Table 5).

Table 3. Univariate and multivariate logistic regression analyses for clinical parameters with direction of RNFL defect in KNHANES V-3, 2012.

	Univariate analysis			Multivariate analysis		
Adjusted factor	Odds Ratio	95% CI	p Value	Odds Ratio	95% CI	p Value
Age (years)	1.013	0.983–1.043	0.412			
Sex	1.798	0.668–4.842	0.246			
SE (D)	0.994	0.844–1.170	0.942			
IOP (mmHg)	1.160	0.977–1.379	0.090	1.132	0.935–1.370	0.204
PPA/Disc Area (ratio)	1.450	0.974–2.159	0.067	1.307	0.883–1.934	0.181
Torsion direction						
Non-torsion	Ref (1.00)		–	Ref (1.00)		–
Superior	0.093	0.01–0.852	0.036	0.088	0.005–1.535	0.096
Inferior	0.201	0.062–0.654	0.008	6.244	1.809–21.558	0.004
Location of PMRE						
No PPA or PMRE < 15°	Ref (1.00)		–	Ref (1.00)		–
Superior	0.626	0.14–2.792	0.539	0.594	0.126–2.811	0.511
Inferior	3.986	1.304–12.19	0.015	4.363	1.270–14.989	0.019

SE = spherical equivalent; D = dioptres; IOP = intra-ocular pressure; PPA = peripapillary atrophy; PMRE = point of maximum radial extent.

Table 4. PMRE versus RNFL defect.

	RNFL defect			
	Superotemporal		Inferotemporal	
PMRE	%*	95% CI*	%*	95% CI*
Superior	48.3	28.8–68.4	9.3	2.7–27.6
Inferior	15.8	7.4–30.4	26.6	15.2–42.2

PMRE = point of maximum radial extent; RNFL = retinal nerve fibre layer.
p = 0.015, Pearson's chi-square test for complex samples.
* Weight-adjusted estimation of percentage in each group.

Table 5. Optic disc torsion versus RNFL defect.

	RNFL defect			
	Superotemporal		Inferotemporal	
Torsion	%*	95% CI*	%*	95% CI*
Superior	16.0	5.1–40.3	1.7	0.3–10.1
Inferior	38.1	17.3–64.5	44.2	23.0–67.7

RNFL = retinal nerve fibre layer; CI = confidence interval.
p = 0.029, Pearson's chi-square test for complex samples.
* Weight-adjusted estimation of percentage in each group.

Discussion

Few population-based investigations of the direction of RNFL defect and the associated factors have been conducted. The present study is the first, moreover, to provide population-based data on the topographic correlation between optic nerve characteristics and RNFL defect in POAG patients.

β-Zone PPA is more frequently found in eyes with glaucoma than in normal eyes (Jonas & Naumann 1989; Jonas et al. 1989; Jonas 2005; Xu et al. 2007). Both size and frequency of β-zone PPA are significantly correlated with variables determinative of glaucomatous optic nerve damage severity, such as neuroretinal rim loss, decrease of retinal vessel diameter, reduced vis-

ibility of RNFL bundles and VF defects (Jonas 2005). In the present study, the prevalence of β-zone PPA in eyes with a single localized RNFL defect was 57.8%, which rate is similar to several previous POAG study findings, which ranged between 62 and 68% (Jonas et al. 1989; Uchida et al. 1999; Teng et al. 2010; Cho & Park 2013). Also, 53.4% of β-zone PPA was located inferiorly (under-the-reference-line PMRE), which results correspond to those of earlier studies, in which β-zone PPA was more commonly located inferiorly (Heltzer 1999; Ehrlich & Radcliffe 2010; Teng et al. 2011; Cho & Park 2013).

Among the other findings, PPA location was spatially correlated with neuroretinal rim loss in the intrapapillary region. Therefore, the PPA location was larger, and the loss of neuroretinal rim was more marked (Jonas & Naumann 1989). Previous reports have shown that PPA conformation helps to determine the location of disc damage and VF abnormalities and that the location of widest PPA is spatially consistent with VF defect location (Anderson 1983; Heijl & Samander 1985). The spatial relationship between VF defect location and β-zone PPA has been demonstrated for both normal-tension glaucoma (NTG) (Park et al. 1996) and POAG (Kono et al. 1999) patients. Cho & Park (2013) noted a significant locational correlation between β-zone PPA and RNFL defect, reporting that RNFL defect appeared within the same hemifield as β-zone PPA, specifically near the PMRE of β-zone PPA. Disrupted normal architecture in β-zone PPA areas, as well as insufficient blood supply to the ONH in the region of β-zone PPA, has been suggested as mechanisms of RNFL defect in β-zone PPA (Teng et al. 2010, 2011; Cho & Park 2013). In current study, significantly, the angular location of the PMRE of β-zone PPA showed a significant association with RNFL defect location.

The present investigation's estimated prevalence rate of optic disc torsion among the cohort of Korean POAG patients aged 19 years or older was 36.5%. Previous studies have reported rates between 28 and 64.7% for the general population (Vongphanit et al. 2002; How et al. 2009) and between 66.6 and 75.9% for myopic glaucoma patients (Park et al. 2012; Lee et al. 2014a,b).

Another finding reported herein is the correlation between optic disc torsion direction and RNFL defect location. The present study showed that the RNFL defect was located in the same direction of the optic disc torsion in 60.2% of cases ($p = 0.029$). If the direction of the optic disc torsion was superior, the damage was manifested in the supertemporal region, and *vice versa*. Park and colleagues (2012) reported that optic disc torsion direction predicts the location of glaucomatous damage in NTG patients with myopia. In another recent study, this one on myopic patients with unilateral glaucomatous-appearing VF defect, Lee et al. (2014a,b) demonstrated fair agreements between optic disc torsion direction and VF defect site. It has been hypothesized that optic disc torsion can put IOP-related stress on optic nerve axons, resulting in initial damage to axons of retinal ganglion cells (Doshi et al. 2007; Park et al. 2012). Although the concordance of the directions of the PMRE of β-zone PPA and of optic disc torsion with RNFL defect location were both statistically significant, there was a higher percentage of inferior disc torsion in the superotemporal RNFL defect group (Table 5); accordingly, the direction of the PMRE of β-zone PPA tends to have more spatial consistency with the RNFL defect location than does the direction of optic disc torsion.

This study has several limitations. First: the use of FDT, instead of standard automated perimetry (SAP), to assess visual-field defects. This might have resulted in over-diagnosis of glaucoma. Although FDT seems to have reduced variability when compared to SAP (Chauhan & Johnson 1999; Spry et al. 2001), both SAP and FDT tests were subject to learning and long-term fluctuation artefacts (Gonzalez-Hernandez et al. 2007; Centofanti et al. 2008; De Tarso Pierre-Filho et al. 2010); thus, again, the single FDT testing algorithm employed in this study could have overestimated the glaucoma prevalence. Nonetheless, whereas FDT is not the standard choice for VF testing of those suspected of having glaucoma, it does offer the benefits of speed and reliability, which are suited for mass screenings; furthermore, FDT can predict glaucomatous functional damage earlier than SAP (Terry et al. 2010). As for the second limitation, the photographic review was performed without masking RNFL defect visibility. Third, as disc haemorrhage was added to the ISGEO category 1 glaucoma-diagnostic criteria, the prevalence of POAG among subjects 19 years and older in the present study (4.2%) was slightly higher than in previous reports (2.0–3.5% of the South Korean population) (Kim et al. 2011; Yoon et al. 2011). Fourth, and finally, due to the limitation of the epidemiological study setting of KNHANES V-3, we could not evaluate gonioscopy data, which is the gold standard of angle-status determination. Instead, we used the Van Herick method (PACD exceeding 1/4 of corneal thickness) to define open angle. While it is indeed likely that primary angle-closure glaucoma (PACG) is less frequent than POAG in Koreans (Kim et al. 2011, 2012; Yoon et al. 2011), unless gonioscopic assessment is included as part of the comprehensive examination of glaucoma cases detected in surveys, the true prevalence of PACG might be underestimated.

In conclusion, the directions of the PMRE of β-zone PPA and of optic disc torsion showed significant associations with RNFL defect location in a population-based sample of Korean POAG patients. Such associations provide a potential utility for prediction of RNFL defect susceptibility location in POAG patients.

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We report our results on behalf of the Epidemiologic Survey Committee of the Korean Ophthalmological Society.