Correlation of pattern of visual field loss by perimetry and anterior chamber angle parameters by anterior segment optical coherence tomography in primary angle-closure glaucoma

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Purpose: To correlate and analyze the pattern of the visual field (VF) defects by perimetry and anterior chamber angle parameters by AS-OCT in primary angle-closure glaucoma (PACG) across varied severity levels on presentation to a tertiary eye care center. Methods: This was a cross-sectional study, which included 323 eyes of clinically diagnosed cases of PACG. Glaucoma severity was categorized according to mean deviation (MD) as mild (-6.00 dB or more), moderate (-6.01 to -12.00 dB), and severe (-12.01 to -30.00 dB). AS-OCT measured the nasal (N) and temporal (T) angle opening distance at 500 µm (AOD 500) and 750 µm (AOD 750), anterior chamber angle (ACA), lens vault (LV), and anterior chamber width (ACW). The VF severity was then correlated with the AS-OCT parameters using statistical analysis. Results: The mean age ± standard deviation (SD) of the patients included in the study was 56.03 ± 8.6 years, with a 1:1.2 gender ratio. The number of eyes with mild, moderate, and severe VFs were 140 (43.3%), 88 (27.24%), and 95 (29.41%), respectively. There was no statistically significant correlation in the mean anterior chamber angle parameters (AOD 500, AOD 750, ACA 500, ACA 750, LV, ACW, and axial length (AL)) among the groups. However, the correlation between AOD 500 and LV thickness was found to be significant ($P = 0.0000$) with a negative Spearman's rank correlation coefficient ($r = -0.3329$). Conclusion: The ACA parameters obtained by AS-OCT along the horizontal axis after elimination of pupillary block by laser peripheral iridotomy do not correlate and cannot be used to assess the disease severity of PACG.

Key words: Anterior chamber angle parameters, AS-OCT, mean deviation, primary angle-closure glaucoma, visual field defects

Primary angle-closure disease (PACD) is more common in the Asian population with the highest prevalence among the Chinese population.[1,2] There is a significantly high incidence of PACG in India, which forms almost half of all adult primary glaucomas seen in a hospital setting.[3-5] Anatomical factors like short axial length (AL), small corneal diameter, shallow anterior chamber (AC), and thick and more anteriorly positioned crystalline lens are regarded as the major risk factors for the development of PACG. Anterior segment imaging modalities such as AS-OCT and UBM yield valuable information on the lens characteristics and angle configuration, but gonioscopy is still the gold standard for the evaluation of the angle.[6,7] Published reports suggest that AS-OCT offers consistent and reproducible measurements of anterior chamber angle parameters over time. The biometric characteristics and pattern of visual field defects in PACG patients have been extensively studied, particularly in the Asian population.[8-10] However, all these studies were performed using Goldmann perimetry, and there exists limited literature correlating the severity of the VF defects using automated perimetry with the anterior segment angle parameters in PACG eyes. The purpose of our study is to explore if there is a correlation between the severity of PACG as defined by automated perimetry and ACA parameters evaluated by AS-OCT.

Methods

Our study is a cross-sectional study on patients with PACG presenting to a tertiary eye care center in South India, from December 2018 to November 2019. An institutional review board approval was obtained (IEC Code: IEC201800302) and the study followed the tenets of the Declaration of Helsinki. Each patient signed informed consent before enrollment for the study.

Primary angle-closure glaucoma (PACG) was defined as eyes with iridotrabecular contact (ITC) >180° and elevated IOP (>21 mmHg) or peripheral anterior synechiae (PAS) and clinical evidence of glaucomatous optic neuropathy.[11] All consecutive patients who have been diagnosed to have stable PACG, 3 – 6 months post-laser iridotomy between 20

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and 70 years of age during the study period were included. The exclusion criteria for the study included unreliable VFs (fixation loss >20%, false-positive responses >33%, false-negative responses >33%), the patients who had VF defects not typical of glaucoma or who had undergone cataract extraction or presented with hazy media, and those who were not willing to participate in the study.

A total of 336 eyes of 168 patients who were diagnosed with PACG were recruited and 13 eyes that did not meet the study criteria were excluded from the study. All patients underwent laser peripheral iridotomy before being recruited for our study. None of the patients had taken any miotic or mydriatic medications at the time of recruitment in our study.

The anterior segment evaluation by slit-lamp biomicroscopy, intraocular pressure (IOP) recording by Goldmann applanation tonometry, and gonioscopic evaluation in dark conditions (with and without indentation) were performed for all patients. Indentation gonioscopy was performed by a glaucoma specialist using a Zeiss-style four-mirror goniolens (Model G-4, Volk Optical, and Mentor, OH). Gonioscopic grading of the angle was done according to the following system. The angles were classified as open angles when a posterior trabecular meshwork or scleral spur was seen on all the quadrants without any evidence of appositional closure or PAS in any of the quadrants. The angles were classified as narrow angles when only Schwalbe’s line and anterior trabecular meshwork were visible in more than three quadrants or any evidence of appositional closure or PAS in any of the quadrants. Additionally, A-Scan biometry (IOL Master 700, Carl Zeiss Meditec AG, Germany) was used to measure AL.

All subjects underwent static automated white-on-white threshold perimetry after recruiting for the study (program 24-2, Swedish Interactive Threshold Algorithm Standard, model 750, Humphrey Field Analyzer, Humphrey Instruments, Dublin, CA). Reliability criteria were adapted from AGIS reliability ratings and were defined by having two of the following characteristics: Fixation losses less than 20%, false-positive responses less than 33%, or false-negative responses less than 33%.

Glaucoma severity was categorized according to the VF-derived MD as Mild (-6.00 dB or more), Moderate (-6.01 to -12.00 dB), and Severe (-12.01 to -30.00 dB). All patients with reliable fields had their data included in the statistical analysis.

AS-OCT (SL-OCT device, Heidelberg Retina Tomograph, HRT II and HRT3, Heidelberg Engineering, Germany) was performed for all patients after laser peripheral iridotomy (LPI) in dark ambient light. Scans were centered on the pupil and were obtained along the horizontal axis (N-T angles at 0 to 180 degrees) by a single operator using the enhanced anterior segment single protocol. Two images were captured for each axis, and a higher-quality image was taken for analysis. In the AS-OCT images, SS is demonstrated as the point where there is a change in the curvature of the inner surface of the angle wall, often appearing as an inward protrusion of the sclera. It may sometimes appear as a highly reflective region.

![Visual field defects](image-url)

**Figure 1:** Pattern of visual field defects in mild, moderate, and severe groups
The software then automatically calculates the various AC parameters. Detection of the scleral spurs was optimized by adjusting the brightness and contrast nature of each image. The temporal and nasal angle parameters were used for analysis as the superior and inferior angle images usually do not have the optimal quality and reproducibility is also difficult. In our study, the measurements were taken by a single trained ophthalmologist in a semi-lit room.

Table 1 illustrates the definitions of the parameters measured using the tools provided by the machine software (software version 2.0.1.88). This semiautomatic software has algorithms defining the borders and curvatures of the AC structures. However, the observer identifies the scleral spurs and anterior lens border for the automated software program to measure the parameters. The angle opening distance (AOD) at 500 µm and 750 µm from the scleral spur, anterior chamber angle (ACA), lens vault (LV), and anterior chamber width (ACW) were generated by the software and recorded. Parameters that were measured on both the nasal and temporal sides of the eye, including AOD at 500 µm from the scleral spur, AOD at 750 µm from the scleral spur, and ACA were represented by the mean values of the nasal and temporal values. They were labeled as AOD 500, AOD750, and ACA, respectively.

All the angle-closure patients were treated with LPI as the standard of care. The crystalline lens nucleus density was graded by the Lens Opacities Classification System III (LOCS III) after pupillary dilatation. For grading of the crystalline lens opacification, the clinical examiners were not masked. All enrolled eyes were subjected to dilated fundus examination and stereoscopic examination of the optic nerve head. The severity of VF loss assessed by perimetry was correlated with the AS-OCT parameters. Demographic and clinical data were collected. Documented data analysis was done and the results were formulated from the study.

**Statistical analysis**

Statistical analysis was performed using STATA version 14 (Texas, USA). Continuous variables were presented in terms of mean ± standard deviation (SD). Discrete variables were presented in terms of frequency and percentage. The normality of the data was checked using Shapiro–Wilks test. ANOVA or Kruskal–Wallis test was used to analyze the continuous variables between more than two groups as per the normality distribution. Spearman’s rank correlation was used to calculate the correlation between the two continuous variables. Since

### Table 1: Anterior segment parameters measured by AS-OCT and their definitions

| Parameters | Definition |
|------------|------------|
| Angle Opening Distance at 500 µm from scleral spur (AOD 500): | The distance between the posterior corneal surface and the anterior iris surface on a line perpendicular to the trabecular meshwork, 500 µm from the scleral spur. |
| Angle Opening Distance at 750 µm from scleral spur (AOD 750): | The distance between the posterior corneal surface and the anterior iris surface on a line perpendicular to the trabecular meshwork 750 µm from the scleral spur. |
| Anterior Chamber Angle (ACA): | The trabecular–iris angle measured with the apex in the iris recess and the arm of the angle passing through a point on the trabecular meshwork at 500 µm (ACA500) and 750 µm (ACA750) from the scleral spur and the point on the iris perpendicularly opposite. |
| Lens Vault (LV): | The perpendicular distance from the anterior lens surface to the horizontal line connecting the two scleral spurs. |
| Anterior Chamber Width (ACW): | The distance between the two scleral spurs. |

### Table 2: Ocular characteristics and distribution of visual field defect patterns across severity levels

| Characteristics | Mild n=140 | Moderate n=88 | Severe n=95 | Total n=323 | P |
|-----------------|------------|---------------|-------------|-------------|---|
| Age (mean±SD), years | 56.28±10 | 54.76±7.59 | 57±10.48 | 56.03±8.57 | 0.4560 a |
| Gender, Male | 42 (50.60) | 14 (30.43) | 20 (51.28) | 76 (45.24) | 0.061 c |
| Female | 41 (49.40) | 32 (69.57) | 19 (48.72) | 92 (54.76) | |
| MD (mean±SD) dB | -3.38±1.50 | -8.76±1.65 | -21.44±6.29 | -10.16±8.44 | 0.0001 k |
| IOP (mean±SD) mmHg | 17.35±3.67 | 16.54±3.94 | 17.86±5.57 | 17.28±4.39 | 0.1929 k |
| Cup Disk Ratio (mean±SD) | 0.62±0.13 | 0.68±0.13 | 0.81±0.12 | 0.69±0.15 | 0.0001 k |
| Axial Length (mean±SD)(mm) | 22.46±0.88 | 22.50±0.95 | 22.65±0.96 | 22.53±0.92 | 0.4231 k |
| Types of VF defects - N (%) | | | | | |
| Generalized depression | 5 (3.57) | 0 | 1 (1.05) | 6 (1.86) | |
| Paracentral scotoma | 16 (11.43) | 10 (11.36) | 1 (1.05) | 27 (8.36) | |
| Seidel’s scotoma | 3 (2.14) | 2 (2.27) | 0 | 5 (1.55) | |
| Double arcuate scotoma | 9 (6.43) | 18 (20.45) | 42 (44.21) | 69 (21.36) | |
| Nasal step | 8 (5.71) | 5 (5.68) | 0 | 13 (4.02) | |
| Arcuate scotoma | 14 (10.0) | 45 (51.14) | 10 (10.53) | 69 (21.36) | |
| Advance visual field defect involving fixation | 0 | 0 | 18 (18.95) | 18 (5.57) | |
| Advance visual field defect not involving fixation | 0 | 4 (4.55) | 23 (24.21) | 27 (8.36) | |
| Normal | 85 (60.71) | 4 (4.55) | 0 | 89 (27.55) | |

One-way ANOVA test; C-Chi-Square test; K-Kruskal-Wallis test
both eyes of the patients were taken into consideration, the correlation between the eyes was checked using the correlation of assessment between eyes formula.\[15\] The correlation was found to be 0.0058, which was insignificant. All statistical probability values ($P$-values) less than 0.05 were considered statistically significant.

### Results

Three hundred and twenty-three eyes of 168 patients fulfilled the inclusion criteria. The eyes were categorized into three groups: mild, moderate, and severe based on the VF MD severity. Demographic characteristics and global VF indices are summarized in Table 2. The mean age of the patients was 56.03 ± 8.5 years, with a 1:1.2 gender ratio. The proportion of patients with mild, moderate, and severe VF defects was $140$ (43.3%), $88$ (27.24%), and $95$ (29.41%), respectively, based on the MD values. The type of VF defect identified was categorized as per the MD group. Despite high IOP and clinically identified glaucomatous disk damage, 89 eyes (27.6%) failed to show any VF defects.

In the mild MD group, most of the eyes were showing paracentral scotomas (11.4%) followed by arcuate scotomas (10.0%) [Fig. 1]. The majority of the eyes in the moderate MD group had arcuate scotomas (51.1%) followed by double arcuate scotomas (20.5%). The severe MD group had double arcuate scotomas (44.2%) most commonly followed by advanced field defects warranting central VF evaluation in 41 (43.2%) eyes. In 18 (19.0%) of these eyes, the advanced field defect was involving central macula fixation, and in the rest (24.2%), the fixation was spared.

The ACA parameters by AS-OCT and axial length were analyzed among the three MD groups [Table 3]. After adjusting for age, sex, axial length, and IOP, there was no statistically significant difference in the mean anterior chamber angle parameters such as AOD500, AOD750, ACA500, ACA750, LV, ACW, and AL among the three groups ($P > 0.05$) [Fig. 2]. Nevertheless, the correlation between AOD 500 and lens vault thickness was studied and was found to be significant ($P = 0.0000$) with a negative Spearman’s rank correlation coefficient ($r = -0.3329$). Hence, it was seen that as LV value increases, AOD500 decreases.

In addition, a comparison of the ACA AS-OCT parameters with the four-mirror gonioscopy findings was found to be statistically significant. The mean AOD 500, AOD 750, ACA 500, ACA 750, and ACW was statistically lower in the eyes with narrow angles ($P < 0.05$). The LV thickness was significantly higher in the eyes with narrow angles ($P = 0.0075$) [Table 4].

### Table 3: Correlating the pattern of visual field loss and anterior chamber angle parameters by AS-OCT

| Anterior Chamber Angle Parameters | Mild n=140 | Moderate n=88 | Severe n=95 | $P$  |
|----------------------------------|-----------|--------------|------------|------|
| AOD 500                          |           |              |            |      |
| Mean (SD)                        | 469.32 (96.28) | 482.46 (116.11) | 493.28 (114.35) | 0.2380* |
| Min-Max                          | 210.5-708 | 244.5 - 808.5 | 204.5 - 727 |      |
| Median (IQR)                     | 470 (403.25 - 528.5) | 487 (390.75-560) | 488 (403.5 - 572.5) |      |
| AOD 750                          |           |              |            |      |
| Mean (SD)                        | 594.71 (128.01) | 594.81 (125.49) | 600.51 (132.79) | 0.9351* |
| Min-Max                          | 185 - 904.5 | 365 - 899.5 | 263.5 - 876 |      |
| Median (IQR)                     | 599.75 (516.25-683) | 585.5 (508.75 - 672.75) | 604.5 (515 - 693.5) |      |
| ACA 500                          |           |              |            |      |
| Mean (SD)                        | 25.17 (4.63) | 25.71 (5.44) | 26.27 (5.64) | 0.2753* |
| Min-Max                          | 12.5 - 35.5 | 14 - 39 | 11.5 - 41.5 |      |
| Median (IQR)                     | 25.5 (22 - 28.25) | 25.75 (21.5 - 29.75) | 26.5 (22-30) |      |
| ACA 750                          |           |              |            |      |
| Mean (SD)                        | 25.70 (4.92) | 25.73 (4.84) | 26.29 (4.93) | 0.6282* |
| Min-Max                          | 8.5 - 37.5 | 15.5 - 35.5 | 12-37 |      |
| Median (IQR)                     | 26 (23-29) | 25.5 (22.25 - 28.5) | 27 (23-30) |      |
| LV                               |           |              |            |      |
| Mean (SD)                        | 750.40 (265.54) | 791.10 (249.66) | 767.55 (262.87) | 0.4324* |
| Min-Max                          | 213-1423 | 239-1370 | 346 - 1476 |      |
| Median (IQR)                     | 732 (568.5 - 911.5) | 771 (612.5-957) | 705 (593-905) |      |
| ACW                              |           |              |            |      |
| Mean (SD)                        | 12.26 (0.71) | 12.25 (0.70) | 12.29 (0.89) | 0.9386+ |
| Min-Max                          | 10.3 - 13.6 | 10.1 - 13.9 | 10.4 - 18.1 |      |
| Median (IQR)                     | 12.2 (11.8 - 12.8) | 12.3 (12 - 12.7) | 12.3 (11.8 - 12.7) |      |
| AL (Axial length)                |           |              |            |      |
| Mean (SD)                        | 22.46 (0.88) | 22.50 (0.95) | 22.65 (0.96) | 0.4231+ |
| Min-Max                          | 20.68 - 24.81 | 20.66 - 27.34 | 21.04 - 25.74 |      |
| Median (IQR)                     | 22.27 (21.76 - 23.13) | 22.42 (21.88 - 23.15) | 22.56 (21.97 - 23.12) |      |

SD - standard deviation; IQR - Inter Quarter Range; * - One-way ANOVA; +-Kruskal-Wallis test
Discussion

To the best knowledge of the authors, this is the first study to assess the possible relationship between ACA parameters obtained by AS-OCT and the severity of PACG in an Indian population. There is, moreover, limited information available in the literature on the association of AS-OCT parameters and PACG severity.\[16]\ Our results seem to suggest that none of the mean ACA parameters measured on AS-OCT had any significant correlation with the severity of PACG (\(P > 0.05\)). Our observations also indicate that many of the ACA parameters obtained on AS-OCT may not be primarily associated with disease severity in PACG. However, one needs to interpret our results with extreme caution, since we have obtained all the ACA measurements after performing LPI. It is not known if the results would have been different had we obtained the AS-OCT parameters before performing LPI and elimination of relative pupillary block and pressure differential across the anterior and posterior chambers, which underlies the mechanism of angle-closure in these eyes. It is possible that the AC depth would have been altered due to changes in the relationship between the peripheral iris and the ACA following the reversal of pupillary block by LPI. Changes in AC parameters after LPI have been reported with significant changes observed in PACG.\[17]\ Future studies need to focus on the various ACA parameters before LPI to obtain a realistic relationship between ACA and PACG severity.

The current literature shows significant differences in spatial patterns of VF defects and structural properties of optic disks among varied levels of glaucoma severity. According to Lau et al.,\[8\] nasal step was the most common field defect in the mild group (>50%) followed by field loss affecting nasal and arcuate areas in the moderate to severe group (>68%). Dhillon et al.\[18\] observed that the presenting VF defects were more severe in chronic angle-closure glaucoma than in acute cases. However, the majority of these studies on the pattern of VF loss in PACG were carried out using kinetic manual perimetry. In our cross-sectional study, we observed that despite clinically diagnosed PACG eyes, visual fields could be normal for most of the eyes in the mild group. The defect most commonly noted in our study was paracentral scotoma nasally in the mild group, whereas in moderate and severe groups, arcuate and biarcuate defects were more prevalent, respectively. Although VF progression cannot be determined from a cross-sectional study, the results from our study suggest that VF defects progress from the nasal region to the arcuate and finally to the paracentral and central region.\[10\]

In our study cohorts, LV was high in eyes with persistent narrow angles. Nongpiur et al.\[19\] measured LV in angle-closure and open-angle eyes and concluded that LV and lens thickness were greater in angle-closure eyes and lens vault is a significant predictor of angle-closure disease regardless of lens thickness or lens position. The greater the LV, the more the iris is pushed anteriorly, which increases the iridolenticular contact and

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### Table 4: Comparison between gonioscopy and the AS-OCT parameters

| Parameters | Open n=186 | Narrow n=137 | P |
|------------|------------|--------------|---|
| AOD 500:   |            |              |   |
| Mean (SD)  | 501.0 (99.75) | 451.36 (111.44) | 0.0000* |
| Min - Max  | 210.5 - 727   | 204.5 - 808.5  |   |
| Median (IQR)| 492.5 (431-572)  | 451.5 (369.5 - 519.5) |   |
| AOD 750:   |            |              |   |
| Mean (SD)  | 612.34 (124.04) | 574.85 (131.46) | 0.0093* |
| Min - Max  | 185 - 879     | 239 - 904.5   |   |
| Median (IQR)| 610.5 (525 - 695.5) | 575.5 (483 - 669.5) |   |
| ACA 500:   |            |              |   |
| Mean (SD)  | 26.71 (4.79)  | 24.18 (5.33)  | 0.0000* |
| Min - Max  | 12.5 - 41.5   | 11.5 - 39     |   |
| Median (IQR)| 26.25 (23-30)  | 24 (20 - 27.5) |   |
| ACA 750:   |            |              |   |
| Mean (SD)  | 26.66 (4.70)  | 24.83 (4.97)  | 0.0005* |
| Min - Max  | 8.5 - 37.5    | 12 - 36.5     |   |
| Median (IQR)| 26.5 (24 - 29.5) | 24.25 (22-28) |   |
| LV:        |            |              |   |
| Mean (SD)  | 733.43 (249.25) | 811.48 (268.92) | 0.0075* |
| Min - Max  | 239 - 1476    | 213 - 1436    |   |
| Median (IQR)| 705 (572-891) | 785 (612-998) |   |
| ACW:       |            |              |   |
| Mean (SD)  | 12.39 (0.79)  | 12.10 (0.69)  | 0.0007* |
| Min - Max  | 10.3 - 18.1   | 10.1 - 13.9   |   |
| Median (IQR)| 12.4 (11.9 - 12.9) | 12.1 (11.7 - 12.6) |   |

* - Two-sample t-test; $ - Mann-Whitney test
narrowrs the iris lens diaphragm resulting in a pupillary block with crowded angle structures. This is confirmed in our study group by the significant negative correlation that was present between LV and AOD 500 regardless of the amount of PAS. Also, in our study, post-LPI angle-closure eyes had significantly higher LV than open-angle eyes. However, the sole effect of LPI in the eyes with high LV thickness has not been evaluated, and hence, cataract surgery may be a better option for these eyes.

Our findings with lesser AOD500, AOD750, ACA500, ACA750, and ACW and higher LV for narrow chamber eyes were consistent with Moghimi et al., who also reported that ACA and AOD500 were less in angle-closure eyes as compared
with controls. Surprisingly, there was no significant correlation between the ACA parameters and mean deviation among mild, moderate, and severe groups. Anterior chamber angle AS-OCT parameters like AOD500, AOD750, ACA500, ACA750, and ACW correlated significantly with the gonioscopy grade as expected.

To our knowledge, this is the first study to correlate the severity of VF loss and ACA parameters in PACG after LPI. In our study, we found that ACA parameters were not correlating with the severity of VF loss for post-LPI patients. However, a comparison of gonioscopy findings and AS-OCT parameters: AOD500, AOD750, ACA500, ACA750, and ACW showed a statistical significance in the eyes with open angles and narrow angles post-LPI LV was higher in the eyes with narrow angles despite patent laser iridotomies.

Our study has some limitations. The major limitation is that the low AS-OCT image quality of the superior and inferior angles led us to use only the nasal and temporal angle parameters for analysis. This could have contributed to a major influence on the results of our study. Second, the subjects were recruited from a tertiary-care glaucoma clinic and the number of enrolled eyes was fairly small. It is possible that our cohort of PACG eyes may not be representative of PACG eyes of the general population. Third, we did not measure the central anterior chamber depth (ACD), because the software in AS-OCT includes only a measuring system of angle parameters after marking the scleral spur. Another limitation is the cross-sectional nature of the investigation, which could not assess the differences in the ACA parameters before and after LPI concerning the severity of VF loss. Any association between angle parameters and disease severity is better defined only in longitudinal, prospective studies.

However, our cross-sectional study on the correlation of severity of VF defects with angle parameters among varied severity of PACG patients adds to the limited literature on Indian ethnic eyes.

Conclusion
ACA parameters measured by AS-OCT after performance of LPI may not correlate with the severity of PACG and cannot be used to assess disease severity before obtaining visual fields and evaluation of optic disks and the retinal nerve fiber layer on dilated fundus examination. It is not known if ACA parameters obtained before LPI are predictive of disease severity and merit further study. We suggest that since perimetry is the assessment of the functional status of the optic nerve head and AS-OCT is the structural evaluation of ACA parameters, it is important to assess the correlation effects of both, which might throw light on our newer aspects in better understanding of PACG management. Future studies with larger populations and different ethnic groups preferably before LPI will help to determine if our findings apply to other populations.

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Conflicts of interest
There are no conflicts of interest.

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