Aim: To investigate the reliability of anterior chamber angle (ACA) measurements in narrow angles and assess the effect of laser peripheral iridotomy (LPI) on these measurements using novel swept-source optical coherence tomography (SS-OCT) technology.

Materials and Methods: In this prospective observational study, patients with gonioscopically narrow angles were enrolled and scheduled for prophylactic LPI. Twelve ACA sections were obtained in each eye using SS-OCT (ANTERION, Heidelberg Engineering, Germany) before and after Nd:YAG LPI. A built-in algorithm calculated ACA measurements after manual identification of the scleral spur and ACA recess. Eight ACA parameters were evaluated: ACA (ACA 500, ACA 750); scleral spur angle (SSA 500, SSA 750); angle opening distance (AOD 500, AOD 750); and trabecular iris space area (TISA 500, TISA 750). The effect of LPI was assessed for each parameter, both nasally and temporally.

Results: Ten patients (18 eyes) were enrolled (mean age, 61.8 ± 13.6 y; 60.0% female individuals). On average, the ACA was wider nasally than temporally (P < 0.004). LPI significantly widened the ACA (range, 26.7–29.4%; P < 0.05). ACA 500 increased by 29.4% (P < 0.001), ACA 750 by 29.2% (P = 0.002), SSA 500 by 27.3% (P = 0.003), SSA 750 by 28.1% (P = 0.001), AOD 500 by 28.6% (P = 0.009), AOD 750 by 28.6% (P = 0.003), TISA 500 by 27.3% (P = 0.004), and TISA 750 by 26.7% (P < 0.200).

Conclusions: SS-OCT ANTERION imaging can be used to reliably measure ACA before and after LPI. ACA, AOD, SSA, and TISA are all valid ACA measurement methods.
November 2019 with gonioscopically occludable angles were prospectively enrolled and scheduled for prophylactic LPI. Patients with uveitis, prior ophthalmological surgery or trauma, and corneal pathologies impairing angle visualization were excluded from the study.

**Angle Imaging**

Anterior chamber images were obtained with an SS-OCT immediately before and 7 to 30 days after Nd:YAG LPI (Tango, Ellex Inc, Australia). For each eye, 6 radial cross-sections of the anterior chamber, 30-degree apart, were acquired in a dark room by a trained clinician (Fig. 1). The operator, device, and light conditions were kept constant through all measurements. To minimize the effect of intertest variability, the average of 2 repeated measurements was used for each value. Thus, image acquisition was performed 4 times in total: twice on each sitting, before and after LPI. To further reduce bias, all sections were subsequently analyzed by 2 trained assessors masked to the patients’ clinical data. The average of their results was used for all analyses. ACA measurements were calculated using a built-in algorithm, requiring the manual positioning of the ACA recess point and scleral spur (SS). Each point was positioned using a predefined standardized protocol: the ACA recess point was positioned on the last pixel of hypodensity between the superior border of the iris and the corneal wall; and the SS point was determined by following the hypodense shadow of the superior border of the ciliary body to the point where scleral fibers change direction or where it meets the anterior chamber border of the iridocorneal junction (Fig. 2). Sections on which either or both of these structures could not be confidently visualized were excluded from the analysis.

The ACAs were assessed using 8 different measurement methods supported by the device’s built-in software: (1) ACA 500 µm (ACA 500) evaluates the angle created between the vectors of the superior margin of the iris and the internal sclero-corneal wall, based at the ACA recess point; (2) scleral spur angle 500 µm (SSA 500) measures the angle between the vectors of the internal sclero-corneal wall and the superior margin of the iris, based at the SS; (3) angle opening distance 500 µm (AOD 500) measures the distance between 2 points 500 µm from the SS, on the internal sclero-corneal wall and on the superior iris margin; (4) trabecular iris space area 500 µm (TISA 500) is a volumetric parameter assessing the area between the ACA recess point, the SS points, an internal sclero-corneal angle point 500 µm from the SS, and a point on the superior margin of the iris, 500 µm from the SS. (5-8) All above-mentioned parameters were also measured using a 750 µm reference distance from the SS. All measurements were assessed both before and after LPI (Fig. 3).

**Laser Iridotomy**

Fifteen minutes before LPI, topical pilocarpine 2% and oxybuprocaaine hydrochloride 0.4% were administered to each patient. A YAG laser (Tango, Ellex Inc, Australia) was used to create an iridotomy with an initial setting of 2.0 mJ. The power of the laser was titrated as required to create a patent iridotomy. Whenever possible, the LPI was positioned in the deepest, most superior crypt, or where the iris appeared the thinnest beneath the superior lid. Nepafenac 1 mg/mL

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**FIGURE 1.** Example of ANTERION SS-OCT 360-degree view of anterior chamber sections (12 anterior chamber angles). N indicates nasal; SS-OCT, swept-source optical coherence tomography; T, temporal. Figure 1 can be viewed in color online at www.glaucomajournal.com.
eyedrops were prescribed hourly on the day of the procedure, and 4 times daily for 1 week thereafter (Fig. 4).

**Statistical Analysis**

Quantitative data were described using means (M) and SDs. Changes in ACA measurements were expressed in percentages. The paired t test analyses were used to assess the differences between measurements performed by the 2 assessors. The average change in ACA parameters before and after LPI treatment was evaluated and adjusted for bilateral inclusion using a mixed-effect model for repeated measures. Statistical analysis was performed using Stata V.14.2 (StataCorp LLC, TX). P-values <0.05 were considered statistically significant.

**RESULTS**

**Protocol Adherence and Image Quality**

Eighteen eyes from 10 patients with occludable angles were enrolled in this study. The average age was 61.8 ± 13.6 years and 60.0% were female individuals. All patients underwent all 4 measurements, except one for whom only 1 post-LPI image could be performed for compliance reasons. A total of 420 angle sections were acquired, showing 840 ACAs: 420 temporal and 420 nasal. Out of these ACA sections, 21.8% (n = 183 ACAs) were excluded because of blurred or incompletely visible ACAs. Among excluded images, 82.0% were sections in the superior and the inferior quadrant, in which the lids or eyelashes were occluding part of the image.

**Temporal Measurements**

All temporal ACA parameters demonstrated a significant widening effect from the LPI procedure. The least significant improvement was recorded with TISA 750, which increased from 0.12 ± 0.04 to 0.16 ± 0.09 mm² after LPI treatment (+25.0%; P < 0.001). The most significant improvement was recorded with TISA 500, which increased from 0.06 ± 0.03 to 0.11 ± 0.06 mm² after LPI treatment (+45.5%; P < 0.001).
All temporal ACA parameter changes are summarized in Supplemental Table 1 (Supplemental Digital Content 1, http://links.lww.com/IJG/A447).

Nasal Measurements
While all nasal parameters showed a mean ACA widening after the LPI procedure, these changes were not statistically significant for 3 of the 8 nasal parameters: SSA 500 increased from 17.9 ± 8.3 to 20.1 ± 11.1 degrees after LPI treatment (+10.9%; \( P = 0.090 \)), AOD 500 increased from 0.17 ± 0.08 to 0.21 ± 0.11 mm after LPI treatment (+19.0%; \( P = 0.200 \)), and TISA 750 increased from 0.13 ± 0.08 to 0.16 ± 0.08 mm\(^2\) (+18.8%; \( P = 0.200 \)). All nasal ACA parameters are summarized in Supplemental Table 1 (Supplemental Digital Content 1, http://links.lww.com/IJG/A447).

360-degree Measurements
The effect of laser treatment was statistically significant for all parameters taking into account all exploitable sections, with the exception of TISA 750 (+26.7%; \( P = 0.200 \)). Supplemental Table 1 (Supplemental Digital Content 1, http://links.lww.com/IJG/A447) presents the changes in ACA measurements for all parameters.

Repeatability of ACA Measurements
There was no statistically significant difference between the parameters measured by the 2 different assessors, with an overall average measurement difference of 2.25%.

Supplemental Table 2 (Supplemental Digital Content 1, http://links.lww.com/IJG/A447) presents all ACA measurements difference between the 2 trained assessors.

DISCUSSION
The present study demonstrates significant ACA widening after LPI as assessed with ANTERION SS-OCT imaging. On average, ACA parameters showed an angle widening of 28.2% after LPI.

Other studies have previously compared ACA measurements before and after LPI using various measurement methods.

The ZAP trial, a large prospective study of 775 eyes, analyzed differences in iridocorneal angle measurements before and after LPI using AS-OCT (Visante, Carl Zeiss Meditec, Dublin, CA).\(^9\) It reported significant angle widening for all AS-OCT measurements 2 weeks after LPI: +66.4% for AOD 500, +65.5% for AOD 750, +44.0% for TISA 500, and +49.3% for TISA 750. Lee et al reported similar effects of LPI after 2 weeks in 32 eyes, with increases of 64.7% and 57.1% in AOD 750 and TISA 750 measurements, respectively.\(^10\) Although both of these studies support the present findings that ACA significantly widens after LPI, they reported a significantly higher change in all AS-OCT measurements except for TISA 500. Three factors may account for such differences in the amplitude of the observed effect. (1) Anatomic factors—Huang et al\(^11\) demonstrated that patients’ age, iris area, and iris curvature had a significant impact on ACA widening after LPI. Although the mean age of our cohort is similar to that of the 2 aforementioned studies, the other factors could not be evaluated. (2) Pupil diameter—dilatation is directly correlated with iris thickness at the scleral spur, and thus, with ACA.\(^12\) Pupil diameter was not recorded in the present study and, therefore, variations in environmental conditions and physiological dilatation may have had an unverifiable effect on ACA measurements. (3) Interassessment variability—a number of studies have reported on the effects of repeated ACA measurements using various techniques. Although some investigators reported variability of around 4.0%, others reported coefficients of variation as high as 10.9%.\(^13,14\) A report by the American Academy of Ophthalmology found post-LPI ACA widening rates ranging from 2.0% to 388.0%.\(^15\) It hypothesized that the most likely reasons for these variations were differences in assessment techniques and reference parameters.

The present study also highlighted the fact that iridocorneal angles were wider nasally than temporally in 70.6% of patients (\( P = 0.004 \)). This was an unexpected finding as Römkens et al\(^8\) had previously reported a wider temporal ACA in young healthy whites using AS-OCT. Conversely, we showed that LPI had a significantly greater effect on temporal ACA measurements compared with nasal ones, suggesting an inverse correlation between baseline angle width and the magnitude of the LPI effect.\(^16\) Although this inverse correlation had already been demonstrated by Lee et al\(^17\) in intereye comparisons, this observation was made on different clock

**FIGURE 4.** Illustration of anterior chamber angle section showing significant angle gain after LPI treatment and specific position of iridotomy (white arrows). (A) nasal side, (B) temporal side. LPI indicates laser peripheral iridotomy. Figure 4 can be viewed in color online at www.glaucomajournal.com.
hours of the same eye in the current study. It is worth noting that all nonstatistically significant ACA parameters in this study were recorded nasally. Once again, this highlights the inverse correlation between baseline ACA opening and LPI effect. Similarly, this suggests that temporal ACA examination could be more reliable and precise to assess angle closure and predict the effect of laser treatment. Moreover, the statistically significant difference observed in the present study between the nasal and temporal side could be linked to the relationship between collector channels’ distribution and trabecular resistance in the different quadrants. Indeed, Zeppa et al.\(^7\) showed that in patients with open-angle glaucoma, in vivo outflow of aqueous humor measured with indocyanine green dye was greater in the inferior quadrants compared with superior ones, and lower in temporal quadrants compared with nasal ones.

Several studies have evaluated the use of SS-OCT and other imaging techniques\(^5\) for the assessment of ACA in healthy individuals,\(^6\)\(^,\)\(^20\) and to compare volumetric parameters between patients with primary angle-closure glaucoma and patients with occludable angles.\(^21\) Xu et al.\(^22\) compared the reproducibility and agreement of angle measurements between SS-OCT (CASIC2, Tomey Japan) and spectral domain OCT (Spectralis OCT, Heidelberg, Germany) in 10 healthy subjects. They found excellent intradevice repeatability and good comparability between the 2 devices. In a separate study, the same group did not identify any significant diurnal variation of angle measurements with AS-OCT.\(^23\) A comparison between gonioscopy, EyeCam, and AS-OCT suggested the superiority of AS-OCT in terms of reliability and efficacy.\(^24\) It was shown that automated gonioscopy imaging devices possess limited resolution in the detection of trabecular meshwork structures compared with AS-OCT.\(^7\)

To the best of our knowledge, this is the first study using the ANTERION SS-OCT to measure ACAs in occludable angles and assess the efficacy of LPI. Eighty percent of manually graded ANTERION SS-OCT images were of sufficient quality for the assessment of ACA. The main reason for the exclusion of scans was the inability to measure angle structures because of interferences caused by eyelashes or eyelids (82%). In total, out of the 420 images obtained from the 18 eyes enrolled, only 1 eye had exploitable images both nasally and temporally leading to the absence of ACA measurements. This may be accounted for by 2 factors: (1) although SS-OCT operators were trained to use the device, they did not interpret the images after the acquisition and may not have realized that some images were of poor quality, and (2) the acquisition time (around 3 s), can make it difficult for some patients to maintain fixation and avoid blinking throughout the examination. Furthermore, analysis of interassessor variability showed that, despite the manual identification of the SS and ACA recess by 2 different assessors, the process did not produce any statistically significant difference in ACA measurements. This suggests that ANTERION SS-OCT offers high interoperator repeatability for the assessment of ACAs.

This study has several limitations. First, the study cohort was small. Second, analyzing iris thickness, curvature and area, and pupil diameter would have permitted to confirm the absence of effect of these factors on the present findings. Similarly, a control group would have provided a comparator to evaluate the repeatability of the measurements. Finally, images were captured at different intervals before and after LPI treatment for each patient. A longer and more standardized follow-up would have increased statistical significance and could potentially have expanded the scope of the analysis to the changes in ACA over time. However, several measures were taken to minimize the effect of these limitations on our results. The control of environmental factors (illumination, operator, device), the use of several repeated measurements and blinded assessors, and mixed-effect model analysis, all contributed to reducing size, repeatability, and observer bias, and resulted in the clear statistical significance of most results. Although this does not completely eliminate all bias, this suggests the validity of the reported results.

In conclusion, this study demonstrates that ANTERION SS-OCT may constitute a reliable examination technique for the assessment of ACA. The fast and noninvasive nature of image acquisition with ANTERION SS-OCT provides a practical alternative to gonioscopy for the evaluation and documentation of angle structures in a routine clinical setting. Moreover, we found that ACA may be asymmetric in white eyes with narrow angles, which may impact the effect of LPI. The clinical relevance of this finding is not known.

**REFERENCES**

1. Phu J, Wang H, Khun SK, et al. Anterior chamber angle evaluation using gonioscopy: consistency and agreement between optometrists and ophthalmologists. *Optom Vis Sci*. 2019; 96:751–760.
2. Foster PJ, Devereux JG, Alsibrik PH, et al. Detection of gonioscopically occludable angles and primary angle closure glaucoma by estimation of limbal chamber depth in Asians: modified grading scheme. *Br J Ophthalmol*. 2000;84:186–192.
3. Lowe RF. Clinical types of angle-closure glaucoma. *Aust NZ J Ophthalmol*. 1988;16:245–250.
4. Ang M, Baskaran M, Werkmeister RM, et al. Anterior segment optical coherence tomography. *Prog Retin Eye Res*. 2018;66:132–156.
5. Qiao Y, Tan C, Zhang M, et al. Comparison of spectral domain and swept-source optical coherence tomography for angle assessment of Chinese elderly subjects. *BMC Ophthalmol*. 2019; 19:142–150.
6. Ni Ni S, Tian J, Marziliano P, et al. Anterior chamber angle shape analysis and classification of glaucoma in SS-OCT images. *J Ophthalmol*. 2014;2014:942367.
7. Porporato N, Baskaran M, Husain R, et al. Recent advances in anterior chamber angle imaging. *Eye (Lond)*. 2020;34:51–59.
8. Römkens HCS, Beckers HJM, Frusch M, et al. Reproducibility of anterior chamber angle analyses with the swept-source optical coherence tomography in young, healthy Caucasians. *Invest Ophthalmol Vis Sci*. 2014;55:3999–4004.
9. Jiang Y, Chang DS, Zhu H, et al. Longitudinal changes of angle configuration in primary angle-closure suspects: the Zhongshan Angle-Closure Prevention Trial. *Ophthalmology*. 2014; 121:1699–1705.
10. Lee KS, Sung KR, Shon K, et al. Longitudinal changes in anterior segment parameters after laser peripheral iridotomy assessed by anterior segment optical coherence tomography. *Invest Ophthalmol Vis Sci*. 2013;54:3166–3170.
11. Huang G, Gonzalez E, Lee R, et al. Anatomic predictors for anterior chamber angle opening after laser peripheral iridotomy in narrow angle eyes. *Curr Eye Res*. 2012;37:575–582.
12. Yunard A, Oktariana VD, Artini W, et al. Comparison of intraocular pressure and anterior chamber angle changes between pilocarpine and laser peripheral iridotomy. *J Curr Glaucoma Pract*. 2019;13:32–36.
13. Martínez-Albert N, Esteve-Taboada JJ, Montés-Micó R. Repeatability assessment of anterior segment biometric measurements under accommodative and nonaccommodative conditions using an anterior segment OCT. *Graefes Arch Clin Exp Ophthalmol*. 2018;256:113–123.
14. Ruiz-Belda C, Piñero DP, Ruiz-Fortes P, et al. Intra-session repeatability of iridocorneal angle measurements provided by a Scheimpflug photography-based system in healthy eyes. *Graefes Arch Clin Exp Ophthalmol*. 2016;254:169–175.

15. Radhakrishnan S, Chen PP, Junk AK, et al. Laser peripheral iridotomy in primary angle closure: a report by the American Academy of Ophthalmology. *Ophthalmology*. 2018;125:1110–1120.

16. Moghimi S, Chen R, Johari M, et al. Changes in anterior segment morphology after laser peripheral iridotomy in acute primary angle closure. *Am J Ophthalmol*. 2016;166:133–140.

17. Lee RY, Kasuga T, Cui QN, et al. Association between baseline iris thickness and prophylactic laser peripheral iridotomy outcomes in primary angle-closure suspects. *Ophthalmology*. 2014;121:1194–1202.

18. Zeppa L, Ambrosone L, Guerra G, et al. In vivo near-infrared fluorescence imaging of aqueous humor outflow structures. *J Ophthalmol*. 2016;2016:8706564.

19. Xu BY, Pardeshi AA, Burkimper B, et al. Differences in anterior chamber angle assessments between gonioscopy, EyeCam, and anterior segment OCT: the Chinese American Eye Study. *Transl Vis Sci Technol*. 2019;8:5–14.

20. Huang W, Gao X, Li X, et al. Anterior and posterior ocular biometry in healthy Chinese subjects: data based on AS-OCT and SS-OCT. *PLoS One*. 2015;10:e0121740.

21. Li F, Zhou R, Gao K, et al. Volumetric parameters-based differentiation of narrow angle from open angle and classification of angle configurations: an SS-OCT study. *Br J Ophthalmol*. 2020;104:92–97.

22. Xu BY, Mai DD, Penteado RC, et al. Reproducibility and agreement of anterior segment parameter measurements obtained using the CASIA2 and Spectralis OCT2 optical coherence tomography devices. *J Glaucoma*. 2017;26:974–979.

23. Xu BY, Penteado RC, Weinreb RN. Diurnal variation of optical coherence tomography measurements of static and dynamic anterior segment parameters. *J Glaucoma*. 2018;27:16–21.