Anterior Chamber Angle and Intraocular Pressure Changes After Phacoemulsification: A Comparison Between Eyes With Closed-Angle and Open-Angle Glaucoma

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**Purpose:** To compare the angle and intraocular pressure (IOP) changes after phacoemulsification between eyes with closed-angle or open-angle glaucoma.

**Methods:** Angle measurements using Visante AS-OCT imaging was performed for a prospective cohort of 24 subjects with closed-angle and 30 subjects with open-angle glaucoma before and 3 months after phacoemulsification. IOP measurement was measured at 6 and 12 months after surgery using Goldmann applanation tonometry as secondary outcome measures.

**Results:** Eyes with closed angles were smaller than those with open angles (mean axial length 22.88 vs. 24.11 mm, \( P < 0.001 \)). Mean anterior chamber depth, area, volume, AOD500, AOD750, ARA, TISA500, and TISA750 increased after phacoemulsification in all eyes regardless of preexisting angle status (all \( P < 0.001 \)). Increase in AOD500, AOD750, TISA500, and TISA750 were greater in eyes with open angles compared with closed angles (\( P = 0.03, 0.04, 0.04, 0.04 \), respectively). Mean IOP decreased by 1.8 and 2.1 mm Hg at 6 and 12 months, respectively, after phacoemulsification for all eyes (\( P < 0.001 \) for both timepoints compared with preoperative baseline). However, postoperative reduction in the mean IOP was not significantly different between eyes with closed and open angles (Mann-Whitney test \( P = 0.32 \) at 6 mo and \( P = 0.75 \) at 12 mo postsurgery compared with preoperative).

**Conclusions:** Angle opening postphacoemulsification was considerable in all eyes. A similar IOP reduction after phacoemulsification was observed in all eyes regardless of angle status.

**Key Words:** AOD, TISA, AS-OCT, cataract, IOP

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Primary angle-closure glaucoma (PACG) is a major cause of blindness, especially in the Asian populations, and eyes with bulky lens have a greater risk of angle closure. Recently, uncomplicated cataract surgery was reported to have an intraocular pressure (IOP)-lowering effect in eyes with both open or closed angles and the angle-opening distance (AOD) was reported as a significant predictor of this IOP-lowering effect. Studies have shown that the angle can widen after phacoemulsification in normal and angle-closure glaucoma eyes. However, few studies made a direct comparison of angle parameters between glaucomatous eyes with closed and open angles. Hu et al reported a greater increase in AOD at 500 μm (AOD500) in narrow angle eyes after phacoemulsification, compared with open angle eyes, and a greater IOP reduction in the narrow-angle group 6 months after surgery. In contrast, Kim et al reported an insignificant difference in AOD500 and trabecular-iris space area (TISA) at 500 μm (TISA500) changes between glaucomatous eyes with closed or open angle after phacoemulsification. Lee et al examined ethnicity as a potential confounder in the anterior segment changes after phacoemulsification, and he concluded significant differences in the postoperative angle changes between Asian and white nonglaucomatous eyes. As evidence has supported the fact that Chinese eyes with occludable angles have smaller anterior chamber depth (ACD) and width compared with white eyes, we felt that further studies are necessary to clarify the potential differences in angle-opening and IOP-lowering effects of phacoemulsification among different ethnic population. We conducted a prospective cohort study to investigate whether angle opening and IOP-lowering effects are greater after cataract surgery in Asian eyes with closed-angle glaucoma compared with open-angle glaucoma (OAG). We examined the anterior chamber angle and IOP changes for 12 months after phacoemulsification in a Chinese majority Asian population.

**PATIENTS AND METHODS**

This is a prospective, comparative study between subjects with closed-angle or OAG who were scheduled for phacoemulsification for visually significant cataracts. They were recruited from the glaucoma clinics at the Singapore National Eye Centre over 2 years (2008 to 2009). Written informed consent was obtained from all subjects, and the study had the approval of the Institutional Review Board of Singapore Eye Research Institute and was performed in accordance with the tenets of the Declaration of Helsinki.

Subjects with closed angles had primary angle closure (PAC) or PACG with medically controlled IOP (≤21 mm Hg) and a patent laser peripheral iridotomy (performed as described elsewhere). Subjects with PAC had either appositional angle closure for 180 degrees or more (non-visibility of the posterior trabecular meshwork on
nonindentational dark room gonioscopy) and raised IOP without glaucomatous optic neuropathy, or at least half clock-hour bands of peripheral anterior synechiae (PAS) for 180 degrees or more. PACG was defined as eyes with PAC associated with glaucomatous optic neuropathy (defined as loss of neuroretinal rim with a vertical cup-to-disc ratio of >0.7 or an intereye asymmetry of >0.2, and/or notching attributable to glaucoma) and visual field loss detected with static automated white-on-white threshold perimetry defined by Glaucoma Hemifield test outside normal limits and/or an abnormal pattern SD with $P < 5\%$ occurring in the normal population.

Subjects with open angles had primary open-angle glaucoma (POAG), defined as eyes with open angles on gonioscopy (where the posterior trabecular meshwork was visible for 360 degrees on nonindentational dark room gonioscopy), and glaucomatous optic neuropathy with corresponding visual field loss. We excluded all patients with secondary angle closure (such as neovascular or uveitic glaucoma), secondary OAG, corneal abnormalities that would preclude accurate gonioscopy, previous laser iridoplasty, or intraocular surgery, and all patients who were unable to provide informed consent or attend the required follow-up appointments.

All subjects underwent a detailed eye examination that included visual acuity measurement using a logarithm of minimum angle of resolution chart (Lighthouse Inc., Long Island, NY), slit-lamp examination (Model BQ 900; Haag-Streit, Bern, Switzerland), stereoscopic optic disc examination with a 78-D lens (Volk Optical Inc., Mentor, OH), IOP measurement by Goldmann applanation tonometry (Haag-Streit, Koniz, Switzerland), and gonioscopy, performed in the dark using a Goldmann 2-mirror lens at high magnification ($\times 16$). Additional indentation gonioscopy with the Sussman 4-mirror lens was used to establish the presence or absence of PAS. All patients had static automated white-on-white threshold perimetry (program 24-2 SITA-standard. Model 750; Humphrey Instruments, Dublin, CA). A-scan biometry (Model US-800; Nidek Co, Ltd., Tokyo, Japan) was used to measure axial length (AL).

We included subjects in this study if their IOP were adequately controlled at baseline using up to 2 topical glaucoma medications (timolol, latanoprost, or brimonidine). Following phacoemulsification, the subjects were instructed to stop using their topical glaucoma medications and the IOP of the subjects were monitored. If the IOP was inadequately controlled (if the IOP was $>21\text{ mm Hg}$), the investigators then added on topical glaucoma medications as needed. None of the subjects received any additional laser or surgical intervention such as laser trabeculoplasty or glaucoma drainage surgery during the follow-up period.

**FIGURE 1.** Angle parameters as defined on anterior-segment optical coherence tomography images (A) ACD, (B) AOD500, TISA500, (C) AOD750, ARA. ACD indicates anterior chamber depth; AOD, angle-opening distance; ARA, angle recess area; TISA, trabecular-iris space area.
Anterior-Segment Optical Coherence Tomography

All subjects underwent imaging using a commercially available AS-OCT (Visante; Carl Zeiss Meditec, Dublin, CA) before their surgery and at least 3 months after their surgery. The details of the AS-OCT imaging technology have been described previously.²² This was performed in dark room conditions (0 Lux) by a single operator who was masked to the results of the clinical ophthalmic examination. Scans were centered on the pupil and were obtained along the horizontal axis (nasal temporal angles at 0 to 180 degrees) using the standard anterior-segment single-scan protocol. To obtain the best quality image, the examiner adjusted the saturation and noise and optimized the polarization for each scan during the examination.

Subsequently, the preoperative and postoperative cross-sectional horizontal AS-OCT images of each subject were evaluated by a single operator (M.E.N.) who was masked to the clinical data of the subjects. These images were processed using a customized software, the Zhongshan Angle Assessment Program (ZAAP, Guangzhou, China).²³ For each image, the only input required from the operator was to determine the location of the 2 scleral spurs as previously described.²⁴ The algorithm then automatically calculated the ACD and the following angle measurements: AOD, angle recess area (ARA), and TISA.

ACD was defined as the distance from the endothelium at the center of the cornea to the anterior pole of the lens. AOD as defined by Pavlin et al²⁵ was calculated at 500 and 750 μm from the scleral spur (AOD500 and AOD750). ARA and TISA were measured according to the guidelines by Ishikawa et al²⁶ and Radhakrishnan et al,²⁷ respectively, as shown in Figure 1. ARA was calculated at 750 μm and the TISA was calculated at 500 and 750 μm (TISA500 and TISA750, respectively). The average values of the nasal and temporal measurements for AOD500, AOD750, TISA500, TISA750, and ARA were used for statistical analysis.

Statistical Analysis

Sample size was calculated using sample size tables for clinical studies.²⁸ Mean postoperative AOD500 and AOD750 changes were the primary outcome measures. Postoperative changes in IOP were secondary outcome measures. A minimal sample size of 17 subjects was required to detect a minimal difference of 0.1 mm of 0.05, a power of 0.8, and a SD of 0.1 mm.

Statistical analysis was performed using SPSS software, version 19 (IBM; SPSS Inc., Chicago, IL). Differences in baseline demographic characteristics between sample subgroups were examined using χ² and Fisher exact tests. Mean values of angle measurement parametric data for eyes before and after the surgery were examined using the paired Student t test. Postoperative changes in angle measurements were then adjusted for their preoperative data and compared between closed and open angle eyes using analysis of covariance (ANCOVA). A P-value of <0.05 was taken as significant.

RESULTS

A total of 73 subjects were recruited for the study and underwent AS-OCT before their surgery. After the preoperative AS-OCT images were analyzed, 8 (11.0%) subjects were excluded from the study for reasons as stated in Figure 2. Of the 65 subjects who had AS-OCT imaging after their surgery, 11 (16.9%) were further excluded. Fifty-four (74.0%) subjects had complete angle measurement data before and after their surgeries, of which 24 (44.4%) had closed angles (PAC and PACG) and 30 (55.6%) had open angles (POAG). Fifty-one (94.4%) subjects were Chinese and 27 (50%) were male.

Table 1 describes the subject ethnicity, sex, and mean age between those with closed and open angle eyes. Eyes with closed angles had shorter AL compared with those with open angles, and a greater proportion of subjects with closed angles were female.

In general, the mean value of all angle parameters AOD500, AOD750, TISA500, TISA750, and ARA significantly increased after phacoemulsification in all eyes (Table 2). The increase in AOD500, AOD750, TISA500, and TISA750 were significantly greater in eyes with open angles compared with those with closed angles (Table 3) after adjustment for preoperative angle measurements. The observed smaller increments in eyes with closed angles were not because of a limitation of angle opening by preexisting PAS, as they remained significant in subset analysis after the exclusion of all eyes with PAS in the nasal and temporal quadrants.

As shown in Table 4, the mean IOP for all eyes significantly decreased from 16.4 mm Hg (preoperative) to 14.6 mm Hg at 6 months and 12 months postsurgery respectively. The mean number of IOP-lowering agents used in all eyes was also significantly decreased at 6 and 12 months postsurgery (0.50 and 0.56, respectively, compared with 0.83 before phacoemulsification, paired-samples t test P = 0.001 and 0.006, respectively). However, when we compared between eyes with closed and open angles, the postoperative reduction in the mean IOP and number of IOP-lowering agents used were not significantly different (Mann-Whitney test P = 0.32 and 0.77, respectively, at 6 mo, P = 0.75 and 0.60 at 12 mo surgery compared with preoperative). When we performed a subset analysis with the exclusion of all eyes with PAS, the postoperative reduction in the mean IOP and number of IOP-lowering agents used were not significantly different between eyes with closed and open angles at all timepoints (Mann-Whitney test P = 0.19 and 0.51, respectively, at
DISCUSSION

Our study found that phacoemulsification resulted in angle opening in Asian eyes with closed-angle and OAG. This agreed with previous studies that angle opening was significant even in eyes with preexisting open angles. IOP was lowered by a mean of 1.8 and 2.1 mm Hg at 6 and 12 months, respectively, after phacoemulsification in Asian eyes with glaucoma. Previous studies reported a mean of 1.6 mm Hg at 3 months in nonglaucomatous eyes with glaucoma.7,8 After Phacoemulsification


table 2. characteristics of subjects with open and closed angles undergoing phacoemulsification

<table>
<thead>
<tr>
<th></th>
<th>Closed Angles (N = 24)</th>
<th>Open Angles (N = 30)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male sex [n (%)]</td>
<td>8 (33.3)</td>
<td>19 (63.3)</td>
<td>0.03*</td>
</tr>
<tr>
<td>Chinese ethnicity [n (%)]</td>
<td>23 (95.8)</td>
<td>28 (93.3)</td>
<td>0.69*</td>
</tr>
<tr>
<td>Age [mean (SD)] (y)</td>
<td>70.6 (5.5)</td>
<td>67.6 (8.1)</td>
<td>0.13**</td>
</tr>
<tr>
<td>Axial length [mean (SD) (mm)]</td>
<td>22.9 (0.9)</td>
<td>24.1 (1.2)</td>
<td>&lt; 0.01**</td>
</tr>
</tbody>
</table>

*P<0.05, t-test. **P<0.001, t-test.

A greater angle-opening effect was observed in eyes with preexisting open angles compared with those with closed angles. On the contrary, Huang et al10 observed a greater increase in AOD500 in eyes in their narrow-angle group compared with those in their open-angle group. In our study, we did not observe any significant difference in the mean postoperative IOP reduction between the OAG group and the closed-angle glaucoma group. On the contrary, Huang and colleagues observed a greater mean IOP reduction of 1.2 mm Hg in their narrow-angle group compared with open-angle group at 6 months after surgery (P = 0.004). In another study, Kim et al18 reported insignificant differences in the post-surgical angle changes between the ACG and OAG groups. In their ACG group, there was a significant postoperative IOP reduction at the final visit (mean follow-up duration of 3.82 ± 4.51 mo), whereas in their OAG group, the mean IOP remained unchanged. The differences in our studies may relate to the complex differences in the way the anterior segment remodels after cataract extraction in glaucomatous versus nonglaucomatous eyes with open or closed angles, or differences between eyes of differing ethnicity. Within the subset of eyes that are traditionally classified as closed angle by gonioscopy, there may even be a wide range of anterior segment anatomic features which may remodel in differing ways after cataract surgery, that explain the differences in our observed angle-opening effects between open versus closed angle eyes. The observation by Barkana et al9 that angle closure may still occur in myopic eyes with long AL supported a hypothesis that angle closure is a condition which is characterized from anterior segment anatomic abnormality, and the ethnic-specific variations in these anterior segment features may explain the difference in ACG prevalence among different populations.

The mechanisms of postphacoemulsification IOP reduction currently remain poorly understood. Angle opening is a part of the anatomic remodeling process when the crystalline lens is removed. Other postulated explanations include a relaxation of the capsular bag which leads to a change in the zonular tension on the scleral spur, and the removal of glycos-amiglycan deposition in the trabecular meshwork by the high fluid flow rate during phacoemulsification. An increase in the phagocytosis of meshwork debris can also occur as a result of the intraoperative trabecular meshwork mechanical insult.30

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TABLE 3. Adjusted Postoperative Changes in Angle and Anterior Chamber Parameters After Phacoemulsification: A Comparison of Eyes With Open and Closed Angles

<table>
<thead>
<tr>
<th></th>
<th>Estimated Mean Change Postoperatively (SE)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>All eyes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 24)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOD500 (mm)</td>
<td>0.18 (0.02)</td>
<td>0.03*</td>
</tr>
<tr>
<td>AOD750 (mm)</td>
<td>0.27 (0.03)</td>
<td>0.04*</td>
</tr>
<tr>
<td>TISA500 (mm²)</td>
<td>0.05 (0.01)</td>
<td>0.04*</td>
</tr>
<tr>
<td>TISA750 (mm²)</td>
<td>0.11 (0.01)</td>
<td>0.04*</td>
</tr>
<tr>
<td>ARA (mm²)</td>
<td>0.14 (0.01)</td>
<td>0.14</td>
</tr>
<tr>
<td>ACD (mm)</td>
<td>2.30 (0.50)</td>
<td>0.27</td>
</tr>
<tr>
<td>All eyes without PAS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 15)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AOD500 (mm)</td>
<td>0.16 (0.02)</td>
<td>0.02*</td>
</tr>
<tr>
<td>AOD750 (mm)</td>
<td>0.23 (0.03)</td>
<td>0.02*</td>
</tr>
<tr>
<td>TISA500 (mm²)</td>
<td>0.05 (0.01)</td>
<td>0.04*</td>
</tr>
<tr>
<td>TISA750 (mm²)</td>
<td>0.10 (0.01)</td>
<td>0.03*</td>
</tr>
<tr>
<td>ARA (mm²)</td>
<td>0.13 (0.02)</td>
<td>0.16</td>
</tr>
<tr>
<td>ACD (mm)</td>
<td>2.19 (0.59)</td>
<td>0.31</td>
</tr>
</tbody>
</table>

*Analysis of covariance P-value of differences between eyes with closed and open angles after adjustment for preoperative measurements, significant differences at P < 0.05.

ACD indicates anterior chamber depth; AOD, angle-opening distance; ARA, angle recess area; PAS, peripheral anterior synechiae; TISA, trabecular-iris space area.

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of the modest magnitude of IOP reduction observed in most studies, combined phaco-trabeculectomy will remain as an indicated surgery for advanced glaucomatous eyes with cataracts and uncontrolled PACG. In patients with early glaucoma, further studies may help to clarify the predictors of those who may benefit from the modest IOP reduction effects of cataract surgery alone. Issa et al\(^{11}\) reported that postsurgical IOP reduction is greater for those with a higher preexisting IOP, and future studies can examine the potential roles of AS-OCT angle parameters in their prediction models.

The difficulty of scleral spur localization is one of the inherent and recognized limitations of AS-OCT angle studies. In our study, 32.2% of our recruited participants were excluded because of indeterminate scleral spur localization on at least 1 AS-OCT image. In a previous community-based study, 25.2% were excluded because of difficulties in the AS-OCT scleral spur determination.\(^{24}\) We addressed this potential limitation with the use of an increased sample size and a single masked experienced observer for all AS-OCT image analysis. We further determined that the demographics of those who were excluded were not significantly different from our subjects who were included in the final analysis. However, the relatively small final subgroup size of 24 subjects with closed angles limited our ability to perform subgroup analyses, after the exclusion of subjects with indeterminate AS-OCT images. Some of our glaucoma subjects were on topical medications used in all eyes after surgery. This might have resulted in differential bias but we were unable to perform subgroup analyses on the IOP changes due to the small subgroup sizes after we stratified the subjects by the number of medications used. However, we were still able to observe a significant reduction in the mean number of IOP-lowering agents used in all eyes after surgery. Our study was also unable to examine the potential confounding role of ethnicity due to the restricted ethnic composition of our subjects.

In conclusion, we observed that phacoemulsification can result in anterior chamber angle opening in Asian eyes with glaucoma and the degree of angle opening was greater in eyes with open angle glaucoma compared to those with closed-angle glaucoma. Similar IOP reduction after phacoemulsification was observed in all eyes regardless of their preexisting angle type. Further studies are needed to verify the relationship among different ethnic populations.

### TABLE 4. Mean Intraocular Pressure Reduction After Phacoemulsification: A Comparison of Eyes With Open and Closed Angles

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>6 mo Postoperative (All Eyes N = 54)</th>
<th>12 mo Postoperative (All Eyes N = 54)</th>
<th>Preoperative</th>
<th>6 mo Postoperative (All Eyes N = 54)</th>
<th>12 mo Postoperative (All Eyes N = 54)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All eyes (N = 54)</td>
<td>16.4 (4.0)</td>
<td>16.4 (4.0)</td>
<td>16.4 (4.0)</td>
<td>&lt; 0.001</td>
<td>16.4 (4.0)</td>
<td>16.4 (4.0)</td>
</tr>
<tr>
<td>Open angle (N = 30)</td>
<td>16.4 (4.0)</td>
<td>16.4 (4.0)</td>
<td>16.4 (4.0)</td>
<td>&lt; 0.001</td>
<td>16.4 (4.0)</td>
<td>16.4 (4.0)</td>
</tr>
<tr>
<td>Closed angle (N = 24)</td>
<td>16.5 (4.1)</td>
<td>16.5 (4.1)</td>
<td>16.5 (4.1)</td>
<td>&lt; 0.001</td>
<td>16.5 (4.1)</td>
<td>16.5 (4.1)</td>
</tr>
<tr>
<td>Closed angle without PAS (N = 15)</td>
<td>16.5 (4.7)</td>
<td>16.5 (4.7)</td>
<td>16.5 (4.7)</td>
<td>&lt; 0.001</td>
<td>16.5 (4.7)</td>
<td>16.5 (4.7)</td>
</tr>
</tbody>
</table>

*Paired-sample \( t \) test \( P \)-value for mean IOP at postoperative timepoint compared with preoperative, significant differences at \( P < 0.05 \).

PAS indicates peripheral anterior synchiae.

### REFERENCES

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