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Original Article

Evaluation of phacoemulsification (ultrasound) cataract surgery on the dynamics of the anterior segment of primary angle closure by AS-OCT

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Abstract: Objective: To explore the changes of anatomical biological parameters and dynamic parameters of the anterior segment (AS) before and after primary angle closure glaucoma (PACG) surgery. Methods: The clinical data of 82 patients (82 eyes) who underwent phacoemulsification in our hospital were retrospectively analyzed and divided into group A (angle closure, n = 38) and group B (normal open angle, n = 44). The anatomical biological parameters and dynamic parameters were compared between the two groups before and after surgery. Results: Compared with group B, group A had smaller anterior chamber depth, higher vaulting, greater iris curvature, and smaller TISA500. Compared with group B, group A had smaller ΔTISA500 and ΔI-area. Compared with group B, the TISA500 was smaller in group A preoperatively, at 1 week, and 1 month after surgery ($P < 0.05$). The iris curvature was larger in group A ($P < 0.05$). The ΔI-area was significantly reduced in group B at 1 week and 1 month after surgery. Group B exhibited smaller ΔI-curv than group A at 1 week and 1 month after surgery ($P < 0.05$). Conclusion: Anterior segment optical coherence tomography (AS-OCT) can effectively monitor the dynamic changes (DC) of the AS caused by phacoemulsification in patients with primary angle closure (PAC). Phacoemulsification can open the primary of PAC patients. However, their iris area does not change significantly. The biological characteristics of the iris itself may be a risk factor leading to PAC.

Keywords: AS-OCT, cataract, phacoemulsification, primary angle closure glaucoma, anterior segment, dynamic changes

Introduction

Glaucoma is an ophthalmic disease with a high prevalence, mainly manifested by visual field defects and optic nerve damage, and the visual impairment that is caused by glaucoma is irreversible [1]. In China, primary angle closure glaucoma (PACG) is the main type of glaucoma, causing serious losses to individuals, families and society, so early diagnosis and effective prevention are necessary [2].

The main cause of PACG is the blockage of the trabecular meshwork by the peripheral iris, obstructing the aqueous humor outflow and leading to chronic or acute elevation of intraocular pressure (IOP). Weinreb et al. [3] have proposed a classification system of angle closure based on different theories, including posterior lens factors, lens factors, plateau iris and pupillary block. Chinese scholars believed that pupillary block is the main mechanism leading to angle closure in PACG [4]. Cross-sectional studies have shown that PACG has specific anatomical features, *i.e.*, shallow anterior chamber, narrow primary angle, small cornea, short eye axis, and thick and relatively anterior lens [5]. Phacoemulsification combined with intraocular lens (IOL) implantation is one of the common surgical approaches in the clinical treatment of PACG, which has the effect of reducing IOP and deepening the anterior chamber [6].

Although this therapy can improve clinical symptoms to some extent, the specific mechanism has not been completely clarified [7]. Clinical studies have also found that some patients still experience elevated IOP after surgery and require secondary surgery or medication to control IOP [8]. Also, previous studies mainly focused on the morphological changes of the anterior chamber after surgery, and there is a lack of analysis on the postoperative anterior segment (AS) dynamics [9, 10]. In view of this, the present study primarily investigated the effect of phacoemulsification on the dynamic changes (DC) of the AS of the anterior chamber using anterior segment optical coherence tomography (AS-OCT), which is innovative and feasible.

Materials and methods

Clinical data

The clinical data of 82 patients (82 eyes) who underwent phacoemulsification combined with IOL implantation were retrospectively analyzed and divided into group A (angle closure, n = 38) and group B (open angle, n = 44). (1) Inclusion criteria for group A: patients singed the informed consent; patients who met diagnostic criteria for PACG by Epidemiological Ophthalmology Society. This study was approved by the medical ethics committee of Jiangsu Province Hospital of Chinese Medicine. Exclusion criteria: poor video quality; withdrawal at midway; poor compliance; complications occurred during or after surgery; diabetes mellitus; presence of neurological disorders affecting pupillary reflex to light; history of intraocular surgery; acute angle-closure glaucoma; secondary glaucoma. (2) Inclusion criteria for group B: patients signed informed consent; patients with normal visual field and fundus; all-round open angle as shown by gonioscopy; IOP < 21 mm Hg; no family history of glaucoma. The exclusion criteria for group B were same as those of group A.

Methods

Surgical procedure: All patients underwent cataract extraction by phacoemulsification combined with IOL implantation using Proparacaine Hydrochloride 0.5% (5 mg) (Approval No. H20103352, Nanjing Ruinian Best Pharmaceutical Co.). After surface anesthesia, a clear corneal incision was made, and then the anterior chamber was filled with viscoelastic agent, followed by continuous circular capsulorhexis, aqueous humor leakage, and phacoemulsification of crystals. Cortex injection was performed and the capsular bag was expanded with viscoelastic agent, in which a folding posterior chamber IOL was implanted. The position of the IOL was adjusted, and the viscoelastic agent was flushed before the corneal incision was closed.

AS-OCT video recording. All AS-OCT video recordings were completed by the same professional at 1 d before surgery, 1 week and 1 month after surgery. (1) Environmental preparation. All lights were turned off, doors and windows were closed in the inspection room to create a dark room. (2) The machine was turned on, and the professional waited for the software to start and enter the OCT interface, and then turned on the video recording software. (3) Patient's data such as birth date, gender and name were entered. (4) The patients sat in the front of the machine, with reasonable adjustment to the height of the table and chair. Resting patients laid their head on the support to keep it motionless for obtaining good quality image. (5) Single-line scanning mode for AS was set, with scanning angle ranging 0-180°. (6) The patients were instructed to gaze at the green dot so that the scanning line passed the corneal vertex, and a vertical band of light passing from the corneal vertex would appear in the image. (7) The patients were instructed to blink, and then continue to gaze at the green dots, press the F9 to start recording, and turn on the light source at a 25 cm away from the temporal side of the patient's contralateral eye in a 45° direction, irradiate the contralateral eye at intensity of the light 1700 lux, and set up a barrier at the position of the bridge of the nose to prevent the examined eye from being irradiated by light. (8) After the pupil was narrowed, the professional pressed F10 to end the recording and the patient closed eyes and rested. (9) The video quality was checked. If there was eye rotation, blinking, *etc*., it was checked again, but the total number of checks should be limited to 3. If the image quality was accepted, the professional saved the video, and exited the scanning mode. (10) The machine was turned off. Video processing. The refractive image distortions were corrected frame by frame, and finally the AS parameters were measured quantitatively: (1) Anatomical parameters of the AS: I-curv, I-area, TISA500, pupil diameter, anterior chamber width, and anterior chamber depth. (2) Calculation of the DC of the AS. With the number of frames as horizontal

Table 1. Comparison of baseline data [n (%)]/($\overline{x}$ ± sd)

Data		Group A (n = 38)	Group B (n = 44)	t/X^2	P
Gender (Cases)	Male	21 (55.26)	23 (52.27)	0.073	0.787
	Female	17 (44.74)	21 (47.73)		
Age (years)		63.15 ± 2.28	63.18 ± 2.25	0.060	0.952
Mean deviation (dB)		-2.42 ± 0.15	-2.41 ± 0.12	0.335	0.738
Eye axis (mm)		23.19 ± 0.52	23.22 ± 0.49	0.269	0.789
Intraocular pressure (mmHg)		14.88 ± 0.29	14.91 ± 0.26	0.494	0.623
Equivalent sphericity (D)		-1.15 ± 0.18	-1.17 ± 0.16	0.533	0.596

coordinates, the pupil diameter as vertical coordinates, the pupil diameter under illumination over time was plotted. The start and end of the frame were located according to change trend of pupil diameter. The SPC is defined as (start frame-end frame pupil diameter)/corresponding (mm/s). The difference between the start frame (dark) and the end frame (light) was indicated by the I Δ, and the DC of the AS included ΔI-curv, ΔI-area, and ΔTISA500.

Outcome measurement

The AS-OCT parameters included iris curvature, iris area, TISA500, vaulting, anterior chamber depth, pupil diameter, and anterior chamber width; the dynamics parameters of anterior chamber included ΔI-curv, ΔI-area, ΔTISA500, and SPC.

Those parameters were compared between the two groups of patients at 1 d before surgery, 1 week and 1 month after surgery.

Statistical methods

SPSS 22.0 was used to analyze the data. Measurement data were expressed as mean ± standard deviation with t-test for normally distributed data and Mann-Whitney U test for non-normally distributed data. Count data were expressed as [n (%)] with chi-squared test for comparison between the two groups. Graphpad Prism 8 was used to illustrate the data. P < 0.05 indicates the presence of statistical significance.

Results

Comparison of baseline data

There was no statistical significance in gender, age, mean deviation, ocular axis, IOP, and spherical equivalent between the two groups (P > 0.05) (**Table 1**).

Comparison of preoperative AS-OCT parameters

Group A exhibited higher vaulting, shallower anterior chamber depth, smaller TISA500 and greater iris curvature than group B (P < 0.05). The two groups showed no significant difference in anterior chamber width, pupil diameter, and iris area (P > 0.05) (**Figure 1**).

Comparison of DC of parameters

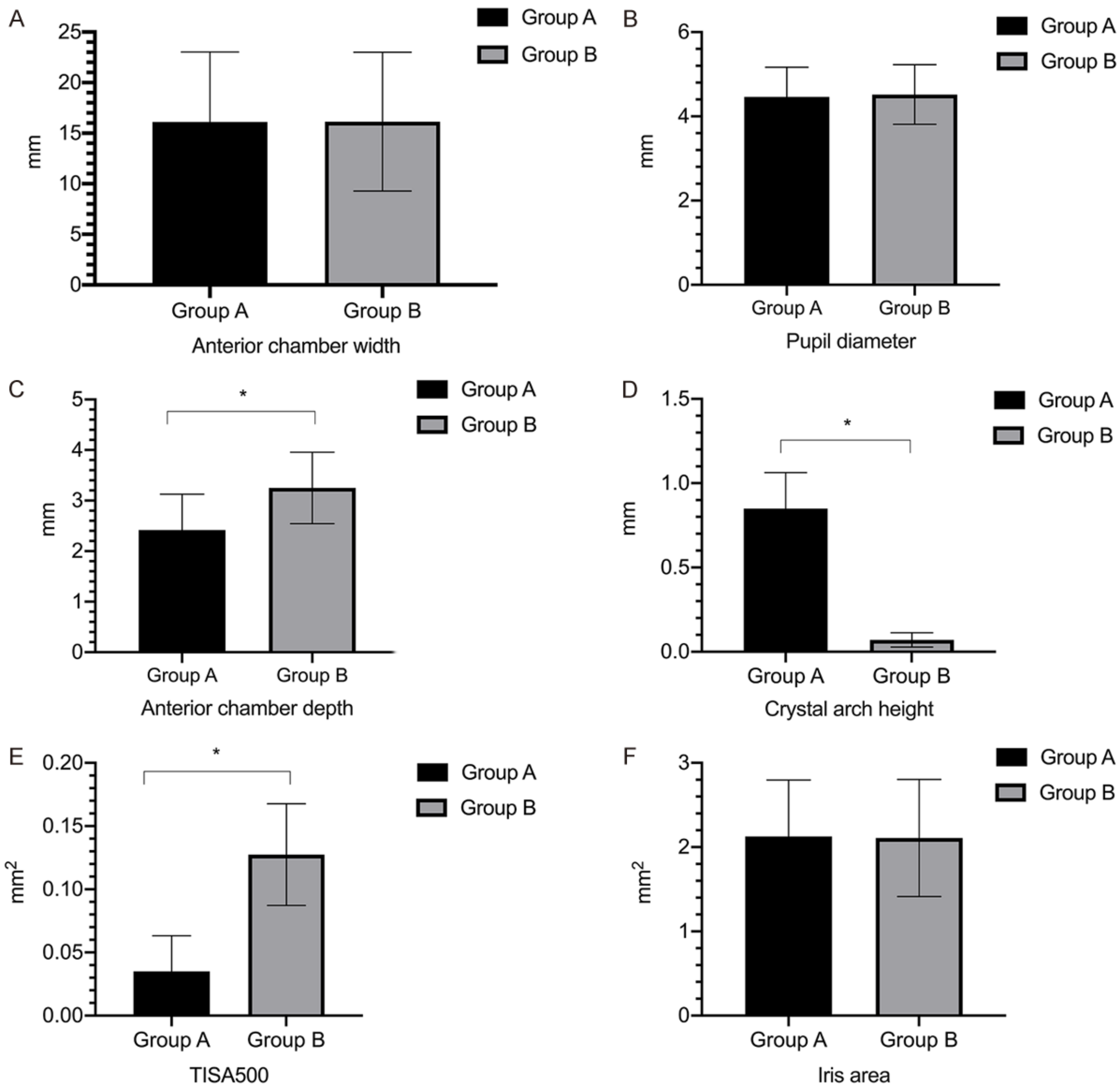
In contrast to group B, group A had smaller ΔTISA500 and ΔI-area (P < 0.05). No significant difference was found between the two groups in the preoperative ΔI-curv and SPC (P > 0.05) (**Figure 2**).

Comparison of TISA500 before and after surgery

TISA500 in group A was (0.013 ± 0.002) before surgery, (0.086 ± 0.001) at 1 week after surgery, and (0.089 ± 0.002) at 1 month after surgery, and the TISA500 in group B at these time points was (0.099 ± 0.003), (0.132 ± 0.002), and (0.145 ± 0.001), respectively. Compared with the preoperative period, TISA500 was wider in both groups at 1 week and 1 month after surgery (P < 0.05). Compared with group B, TISA500 was smaller in group A at these time points (P < 0.05) (**Table 2**).

Comparison of iris curvature before and after surgery

The iris curvature in group A was (0.282 ± 0.001) before surgery, (0.156 ± 0.002) at 1 week after surgery, and (0.112 ± 0.001) at 1 month after surgery, and the iris curvature in group B at these time points was (0.162 ± 0.001), (0.098 ± 0.001), and (0.109 ± 0.019), respectively. Compared with the preoperative period, the iris curvature was smaller in both groups at 1 week and 1 month after surgery (P



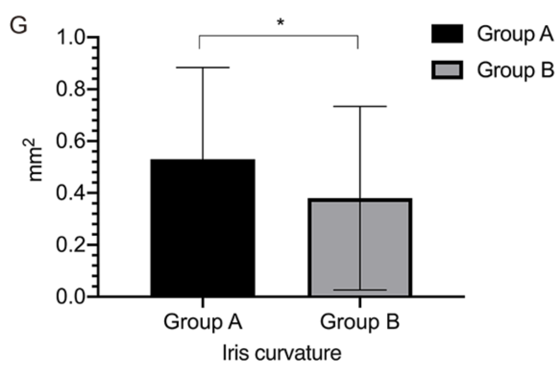


Figure 1. Comparison of preoperative AS-OCT parameters between the two groups. A: Anterior chamber width, *P* > 0.05; B: Pupil diameter, *P* > 0.05; C: The anterior chamber depth, *P* < 0.05; D: Crystal arch height, *P* < 0.05; E: TISA500, *P* < 0.05; F: Iris area, *P* > 0.05; G: Iris curvature, *P* < 0.05. *indicates comparison with group B, *P* < 0.05.

< 0.05). Group A showed larger iris curvature at 1 week after surgery than group B (*P* < 0.05), but there was no significant difference in iris curvature between the two groups at 1 month after surgery (*P* > 0.05) (**Table 3**).

Comparison of SPC before and after surgery

SPC in group A was (1.801 ± 0.002) before surgery, (1.489 ± 0.003) at 1 week after surgery, and (1.498 ± 0.001) at 1 month after surgery,

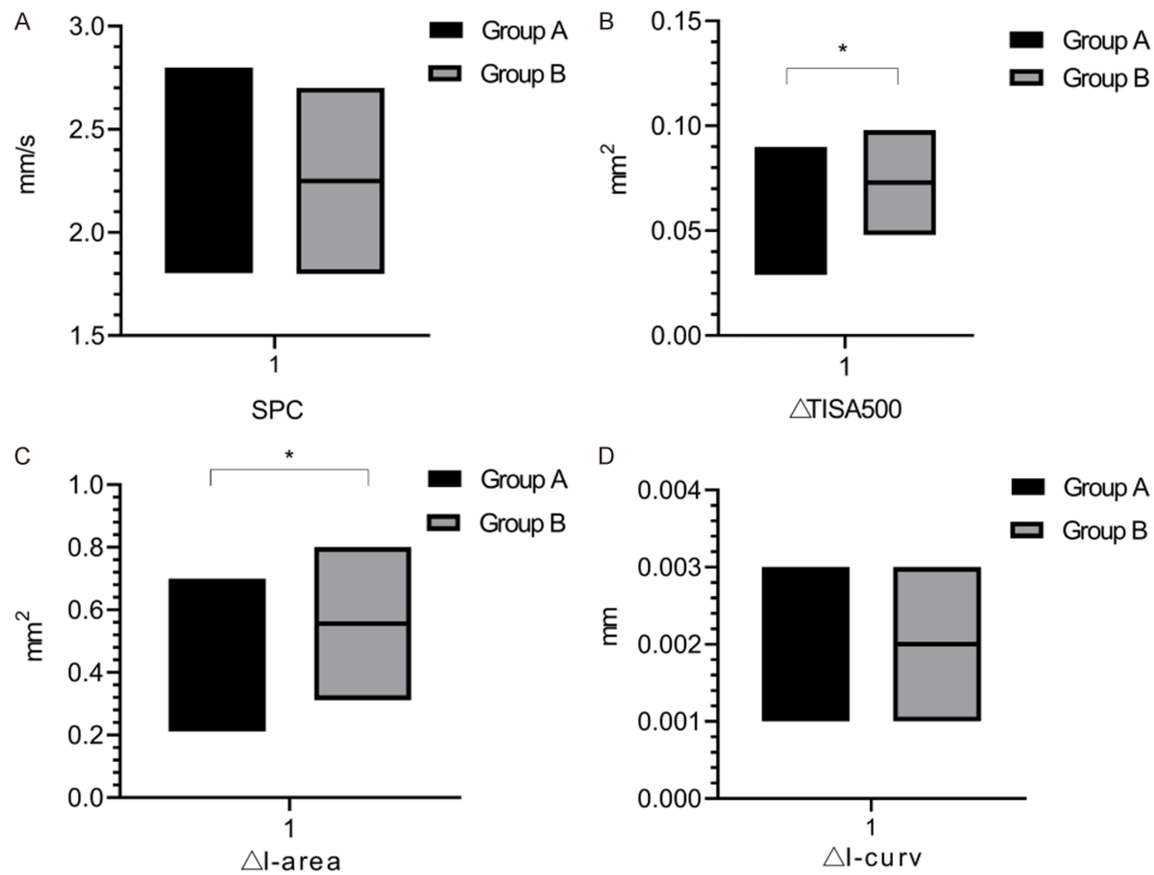


Figure 2. Comparison of preoperative parameters between the two groups. A: SPC, $P > 0.05$; B: ΔTISA500, $P < 0.05$; C: ΔI-area, $P < 0.05$; D: ΔI-curv, $P > 0.05$. *indicates comparison with group B, $P < 0.05$.

Table 2. Comparison of TISA500 ($\bar{x}$ ± sd)

Group	Preoperative	1 week after surgery	1 month after surgery
Group A (n = 38)	0.013 ± 0.002*	0.086 ± 0.001*	0.089 ± 0.002*
Group B (n = 44)	0.099 ± 0.003	0.132 ± 0.002	0.145 ± 0.001
t	150.168	128.511	163.654
P	0.000	0.000	0.000

Note: *compared with group B, $P < 0.05$.

Table 3. Comparison of iris curvature ($\bar{x}$ ± sd)

Group	Preoperative	1 week after surgery	1 month after surgery
Group A (n = 38)	0.282 ± 0.001*	0.156 ± 0.002*	0.112 ± 0.001
Group B (n = 44)	0.162 ± 0.001	0.098 ± 0.001	0.109 ± 0.019
t	541.867	169.499	0.971
P	0.000	0.000	0.334

Note: *compared with group B, P < 0.05.

and SPC in group B at these time points was (1.802 ± 0.015), (1.491 ± 0.018), and (1.501 ± 0.015), respectively. SPC was significantly slower after surgery in both groups ($P < 0.05$). However, no significant difference was observed between the two groups at 1 week and 1 month after surgery ($P > 0.05$) (**Table 4**).

Comparison of ΔI-curv, ΔI-area and ΔTISA500 before and after surgery

In group B, ΔI-curv at 1 week and 1 month after surgery were significantly reduced compared with preoperative values ($P < 0.05$); and they were smaller in group B than in group A ($P < 0.05$) (**Figure 3**). In contrast to group B, group A had a smaller preoperative ΔI-area ($P < 0.05$). ΔI-area was reduced in group B postoperatively ($P < 0.05$). Group A had a larger ΔI-area than group B after surgery ($P < 0.05$) (**Figure 3**).

Table 4. Comparison of SPC ($\bar{x}$ ± sd)

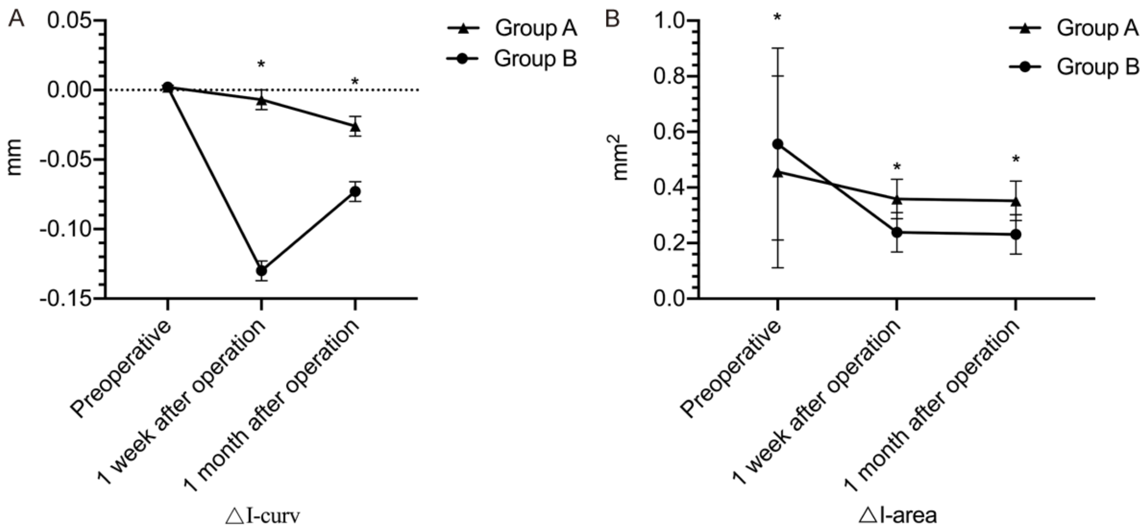
Group	Preoperative	1 week after surgery	1 month after surgery
Group A (n = 38)	1.801 ± 0.002	1.489 ± 0.003	1.498 ± 0.001
Group B (n = 44)	1.802 ± 0.015	1.491 ± 0.018	1.501 ± 0.015
t	0.408	0.676	1.229
P	0.685	0.501	0.223

ΔTISA500 did not change until 1 month after surgery in group B ($P < 0.05$). The two groups showed no significant difference in ΔTISA500 ($P > 0.05$) (**Figure 3**).

Discussion

China has a high prevalence of PACG, and recent clinical studies have shown that DC of the AS is also involved in the angle closure in addition to anatomical factors [11, 12]. It has been found that the parameters of AS will change after anti-glaucoma surgery of atrial angle closure, which is helpful not only to understand the mechanism of surgical treatment, but also to understand the correlation between AS dynamics and angle closure [13, 14]. A common surgical option in the clinical treatment of PACG is cataract phacoemulsification combined with IOL implantation, which can deepen the anterior chamber and reduce IOP [15, 16]. However, follow-up studies have shown that some patients also have elevated IOP after surgery and require secondary surgery or medical intervention [17]. Therefore, this study focused on the effect of surgery on the DC of the AS. The results showed that compared with the preoperative period, TISA500 became wider in both groups at 1 week and 1 month after surgery, suggesting that cataract surgery can prompt the opening of the angle in patients with PACG. Man et al. [18] quantified the angle parameters using UBM, with AOD500 (angle-opening distance at 500 μm) as an indicator of angle width. The results showed that 1 year after phacoemulsification, the patients' AOD-500 increased significantly, *i.e.*, the angle became wider. In this study, not only the angle became wider after surgery, but also the iris curvature decreased significantly at 1 week and 1 month after surgery compared with that before surgery, suggesting a gradual flattening of the iris after surgery. The pupil block theory is widely accepted as the mechanism of atrial angle closure, which refers to the contact of the posterior surface of the iris with the anterior capsule membrane of the crystal, resulting in a significant increase in the resistance to aqueous flow from the posterior to the anterior chamber, and leading to increased pressure in the posterior atrium and the expansion of the iris tissue toward the anterior [19, 20]. In this study, the preoperative curvature of the iris in group A was greater than that in group B, suggesting that compared with the open angle group, the iris of the angle closure group was more distended, which was consistent with the characteristic of pupil tissue. At 1 month after surgery, the curvature of the iris of the two groups decreased, suggesting that phacoemulsification can relieve the pupil block and promote the flattening of the iris.

The results of this study showed that the preoperative ΔI-area in group A was smaller than that in group B ($P < 0.05$), suggesting that when the pupil was dilated, the iris area reduction was relatively small in the angle closure group, which was highly consistent with the analysis of Quigley et al. [21]. Tanito et al. found that as the pupil dilates, the iris area decreases, and the reduced area in the closed angle group is less than that in the open group, suggesting that more iris area is retained in primary closed angle glaucoma when the pupil is dilated, which may lead to angle closure or angle stenosis [22]. In the present study, ΔI-area of group B was significantly reduced at 1 week and 1 month after surgery, while that of group A was not significantly changed, suggesting that the cataract surgery did not change the "sponge-like" features of the iris in the angle closure eyes, and this DC may be a main cause of the closure of the angle. Secondly, this study also showed that the preoperative ΔTISA500 in group A was smaller than that in group B, suggesting that the increase in TISA500 in the angle closure group was smaller than that in the open angle group under the light stimulus. ΔTISA500 at 1 month after surgery was significantly reduced compared to value at 1 d before surgery, which is different from the results of See et al. [23], which may be caused by different surgical methods. Through LPI surgery, See et al. observed the changes of ΔTISA500 in patients with angle-closure glaucoma, and the results showed that ΔTISA500 increased significantly after surgery compared with the pre-



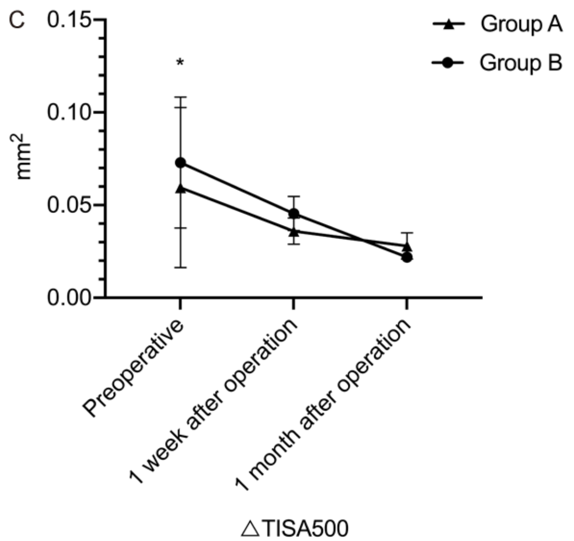


Figure 3. Comparison of ΔI-curv, ΔI-area and ΔTISA500. In group A, no significant difference was found in ΔI-curv, ΔI-area and ΔTISA500 at the three time points. A: In group B, ΔI-curv at 1 week and 1 month after surgery was significantly reduced than that before surgery (P < 0.05); group B showed smaller ΔI-curv at 1 week and 1 month after surgery than group A (P < 0.05). B: Before surgery, group A had smaller ΔI-area than group B (P < 0.05); in group B, ΔI-area at 1 week and 1 month after surgery was significantly reduced than that before surgery (P < 0.05); group B showed smaller ΔI-area at 1 week and 1 month after surgery than group A (P < 0.05). C: In group B, ΔTISA500 at 1 month after surgery was significantly reduced than that before surgery; compared with before surgery, there was no significant difference in ΔTISA500 at 1 month after surgery between the two groups. *indicates comparison with group B, P < 0.05.

operative period, probably because LPI surgery increased the width of the angle and reduced the pressure difference between the anterior and posterior chamber, which reduced the force acting on the iris and accelerated the movement. Zheng et al. [24] found that SPC was significantly accelerated after LPI surgery. The results of this study showed that compared with the preoperative period, SPC was significantly slower in both groups at 1 week and 1 month after surgery (P < 0.05), suggesting that although phacoemulsification could flatten the iris and open the atrial angle, there was a significant difference in the change of AS dynamics compared with LPI surgery, which may be due to the differences between the two surgical interventions. Unlike LPI surgery, cataract phacoemulsification requires the placement of surgical instruments into the anterior chamber of the eye. During the operation, the lens nucleus is split by an ultrasound energy probe, and then the cortex is aspirated, followed by the insertion of the intraocular lens. The operations are performed in the AS of the eye, and it is difficult to avoid damage to the intraocular tissues by perfusion pressure and ultrasound energy [25, 26]. In conclusion, the ultrasound energy applied during the phacoemulsification may damage tissues of the AS and slow down AS motion, but it does not affect the postoperative decrease in IOP or increase in the angle width. The correlation between angle closure and the speed of AS motion change needs to be analyzed further in the future [27].

In summary, AS-OCT can effectively record the effect of cataract phacoemulsification surgery on the DC of the AS. It can close the angle in patients with angle closure. Compared with patients with open angle, the iris area in patients with angle closure did not change significantly, and the biological characteristics of the iris itself may be a key factor involving in the closing of the primary angle.

However, there are some limitations in this study. We only conducted a comparative analysis of the iris and angle parameters of the nasal temporal side, and the software could not calculate the iris volume, but could only use the cross-sectional area of the iris for comparison. This requires analysis in the future in-depth exploration.

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Disclosure of conflict of interest

None.

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