Clinical value of anterior segment optical coherence tomography-assisted Wuerzburg bleb classification system for bleb assessment following trabeculectomy

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Abstract. The Wuerzburg bleb classification system (WBCS) is an established tool for evaluating filtering blebs, while anterior segment optical coherence tomography (ASOCT) provides detailed information on inner bleb structure. The present study aimed to investigate the clinical value of ASOCT-assisted WBCS following trabeculectomy (TRAB). The present prospective, observational study included eyes that underwent TRAB. Bleb assessments using the WBCS were based on the image acquired by ASOCT. The WBCS scores were assessed at postoperative week 2 and postoperative month (POM) 1, 2, 3, 6 and 12. The surgical outcomes at 1 year were determined as success or failure. Spearman's analysis explored the correlation of WBCS scores with intraocular pressure (IOP) and surgical outcome. A total of 32 eyes from 32 patients were included in the present study. The WBCS total score significantly correlated with IOP at POM 1, 2, 3, 6 and 12 ($P<0.05$). For single parameters, microcysts demonstrated a good correlation with IOP at POM 1, 2, 3, 6 and 12 ($P<0.05$). The WBCS total score correlated well with surgical outcome at POM 2, 3, 6 and 12 ($P\leq 0.005$). Microcysts, vascularity and encapsulation significantly correlated with surgical outcomes ($P<0.05$). The results of the present study suggest that ASOCT-assisted WBCS is a simple and effective measurement system for blebs after TRAB in clinical practice, which correlates well with IOP and surgical outcomes. Blebs with a higher WBCS total score and microcysts score in the early postoperative period, such as at POM 2 and 3, are less likely to have surgical failure in the long term.

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Introduction

Trabeculectomy (TRAB) is one of the most frequently performed and an effective surgical methods to manage glaucoma worldwide (1,2). Its success depends on the formation and maintenance of the filtering bleb. Bleb scarring is the leading cause of surgical failure. Antimetabolites, including mitomycin C and 5-fluorouracil (5-FU), are commonly used intraoperatively or postoperatively to prevent bleb scarring. Since fibrosis after surgery may not be completely prevented, an effective method for clinicians to observe potential signs of scarring is essential for appropriate postoperative management. The literature revealed that bleb morphology is an indicator to predict long-term prognosis, besides intraocular pressure (IOP) (3,4). The bleb morphological features may get worse before the IOP worsens (5). Multiple studies have focused on developing a classification system to evaluate the bleb, resulting in the invention of different classical bleb grading systems (3,4,6,7). Several classifications have been applied in various studies and have indicated good interobserver agreements, such as the Moorfield Bleb Grading System (MBGS) (6), the Indiana Bleb Appearance Grading Scale (IBAGS) (4), the Mainz Bleb Appearance Grading System (MaBAGS) (7) and the Wuerzburg Bleb Classification System (WBCS) (3,8) (Table I). Compared with other grading systems, the WBCS is much simpler to apply in clinical practice. It was developed in 1998 and evaluates blebs according to four parameters, namely vascularity, corkscrew vessels, encapsulation and microcysts (3). Previous cross-sectional and retrospective studies suggested that the WBCS correlates well with the IOP after TRAB (3,8,9).

Since bleb grading systems are based on the slit-lamp examination or photograph, apparent defects are detected it has obvious shortcomings when assessing the internal bleb structure (7,10,11). In the last few years, imaging techniques have been utilized to investigate the bleb structure. Anterior segment optical coherence tomography (ASOCT) has become the most favorable procedure, as it allows quick, non-contact, high-resolution bleb imaging. It provides details of bleb structure, such as the thickness of the bleb wall, microcysts and subconjunctival cavity. Numerous studies have investigated the morphologic characteristics of blebs using ASOCT to identify the parameters that correlate with IOP or surgical outcomes (12,13). ASOCT is also useful for assisting the bleb intervention in clinical practice (14).

In the present study, it was hypothesized that the combination of ASOCT and WBCS provides more comprehensive bleb data and is easier to apply in clinical practice and research compared with evaluations using the ASOCT or WBCS alone. To the best of our knowledge, the present study was the first to evaluate the correlation between ASOCT-assisted WBCS and IOP, as well as the predictive value of ASOCT-assisted WBCS for long-term surgical outcomes. We also found the parameter that is most valuable for predicting long-term surgical success in the present study.

Patients and methods

Patient selection. The present study was a prospective, observational study. Patients that were admitted to The Third People's Hospital of Chengdu (Chengdu, China) for TRAB surgery from January to June 2021 were recruited. The inclusion criteria were as follows: i) Aged between 18 and 80 years; ii) diagnosed with primary glaucoma, including primary open-angle glaucoma, chronic primary angle-closure glaucoma and normal-tension glaucoma; iii) IOP >21 mmHg with medication or medication intolerance; iv) no previous glaucoma laser treatment in the last month; v) no previous intraocular surgery in the last 3 months; vi) without any systemic disease that would affect wound healing and participating in the routine follow-ups; and vii) no allergic history of antimetabolites. The protocol was approved by the Ethical and Research Committee of The Third People's Hospital of Chengdu (Chengdu, China) and written informed consent was provided by each patient.

Preoperative data. Demographic information of the patients was recorded, including age, sex, number of anti-glaucoma drops, as well as any related ocular or systemic disease history. All patients underwent an exhaustive ophthalmic examination preoperatively, including best-corrected visual acuity (BCVA), the average IOP of three instances using a tonometer (Reichert 7 auto-tonometer; Reichert, Inc.), central corneal thickness, visual field (Humphrey® Field Analyzer 3; Carl Zeiss Meditec, Inc.), disc damage likelihood scale (DDLS) and average retinal nerve fiber layer thickness measured by OCT (Cirrus HD-OCT; Carl Zeiss Meditec, Inc.).

Trabeculectomy and follow-ups. The patients in the present study were subjected to standard clinical practice. All of the eyes underwent fornix-based trabeculectomy with 5-FU (10 ml/0.25 mg; Jinyao Meditec) by an experienced glaucoma specialist. Any anti-glaucoma drops with Prostaglandin analogue were ceased 3 days before the surgery. Postoperative medications included topical steroid drops (prednisolone acetate, 1%) four times per day, which was tapered off between 4-6 weeks, and antibiotic drops (levofloxacin, 0.5%) four times per day for 2-3 weeks. Follow-up visits were set at 2 weeks and 1, 2, 3, 6 and 12 months following surgery. Examinations at each visit included BCVA, IOP, slit-lamp examination and bleb imaging using ASOCT. Visual field and DDLS were measured at postoperative month (POM) 6 and 12.

ASOCT-assisted WBCS. ASOCT images of blebs were acquired by a single technician blinded to the clinical examination result using the SPECTRALIS® Anterior Segment Module system (OCT; Heidelberg Engineering, Inc.). The patients were requested to look down, following which the examiner lifted the upper eyelids gently for optimal exposure. Raster 10-line horizontal scans (21 images; line length, 8.3 mm) that centered on the apex of the bleb were acquired. A single ophthalmologist scored two WBCS parameters (vascularity and corkscrew vessels) under a slit-lamp and scored the other two parameters (encapsulation and microcysts) using ASOCT images (representative images provided in Figs. 1-3) without knowing the IOP. The scoring of microcysts was based on their extent and location on the ASOCT images. Images of blebs were also acquired under a slit-lamp (BX900; Haag-Streit).

Surgical outcomes. The surgical outcomes of each eye at 1 year were defined as follows: i) Success (5≤21 mmHg IOP without topical glaucoma medication or bleb needling); or ii) failure (5≤21 mmHg IOP with topical glaucoma medication or bleb needling, or IOP >21 mmHg).

Statistical analysis. Variables were presented as the mean ± the standard deviation (for normal distributions) or medians and interquartile ranges (IQR; for non-normal distributions). The Shapiro-Wilk test was used to evaluate the normality of data distribution. Spearman's coefficient was used to assess the correlations between WBCS scores and IOP. The Friedman test followed by the Nemenyi test was used to compare the difference of scores among visits, while repeated-measures ANOVA followed by the Bonferroni test was used to compare IOP among visits. Comparisons between two outcome groups were analyzed using the Mann-Whitney U-test. The data were analyzed using SPSS version 20.0 (IBM Corp.). P<0.05 was considered to indicate statistical significance.

Results

Demographic and preoperative information. A total of 32 patients (32 eyes) were included in the present study. Table II summarizes the baseline demographic and preoperative clinical characteristics. The average age of all individuals was 59 (53.5, 63.2) years, with 9 males and 23 females participating.

WBCS scores. The median WBCS total score was 11.0 (IQR, 10-11) at postoperative week (POW) 2, 10 (IQR, 10-11) at POM 1, 10.5 (IQR, 9.25-11) at POM 2, 10 (IQR, 9-11) at POM 3, 10 (IQR, 9-11) at POM 6 and 10 (IQR, 10-11) at POM 12. A box-and-whiskers diagram indicated that the total score was the highest at POW 2, then declined at POM 1 and stabilized after POM 3 (Fig. 4). The Friedman test followed by the Nemenyi test did not indicate any significant difference between any two postoperative visits within 1 year (P>0.05).

Among the four single parameters in the WBCS, there were no significant differences in vascularity (median, 2; P>0.05), corkscrew vessels (median, 3; P>0.05) nor encapsulation (median, 3; P>0.05) scores between any two visits. The microcysts score had a median of 3 (IQR, 3-3) at POW 2 and 3 (IQR, 2-3) at POM 1, and then gradually declined from 3 (IQR, 2-3) at POM 2 to 2 (IQR, 1.25-3) at POM 3. The microcysts score became more stable after POM 3 (Fig. 5). The Friedman test

Table I. Wuerzburg bleb classification system.

Item	Scoring
Vascularity	3=avascular
	2=similar to adjacent conjunctiva
	1=increased
	0=massive
Corkscrew vessels	3=none
	2=in one third
	1=in two thirds
	0=entire bleb
Encapsulation	3=none
	2=in one third
	1=in two thirds
	0=entire bleb
Microcysts	3=entire bleb
	2=lateral or medial of the flap
	1=over the scleral flap
	0=none

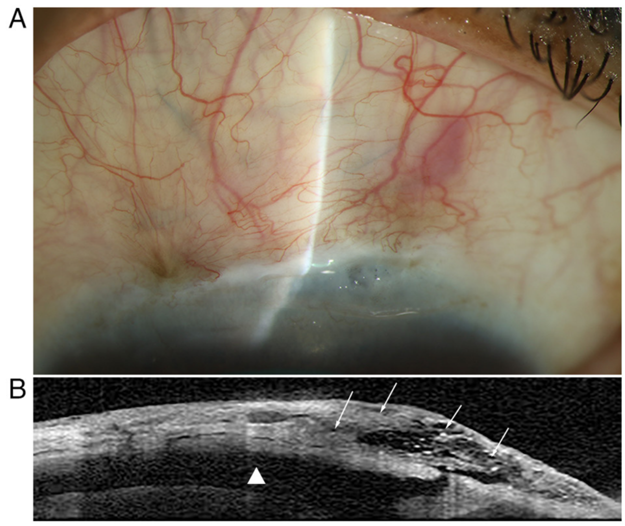

Figure 2. Anterior segment optical coherence tomography-assisted WBCS evaluation of filtering blebs. (A) Bleb photograph and (B) optical coherence tomography scan of a patient (female; age, 63 years) at postoperative month 6. Arrows indicate microcysts and the triangle indicates the supra-scleral fluid space. WBCS score: Vascularity, 2; corkscrew vessels, 3; encapsulation, 3; and microcysts, 2. WBCS, Wuerzburg bleb classification system.

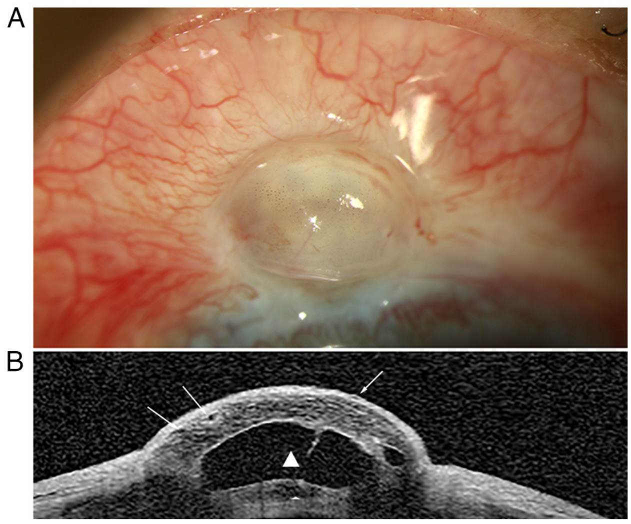

Figure 1. Anterior segment optical coherence tomography-assisted WBCS evaluation of filtering blebs. (A) Bleb photograph and (B) optical coherence tomography scan of a patient (female; age, 61 years) at postoperative month 2. Arrows indicate microcysts and the triangle indicates the encapsulated cavity. WBCS score: Vascularity, 1; corkscrew vessels, 3; encapsulation, 2; and microcysts, 1. WBCS, Wuerzburg bleb classification system.

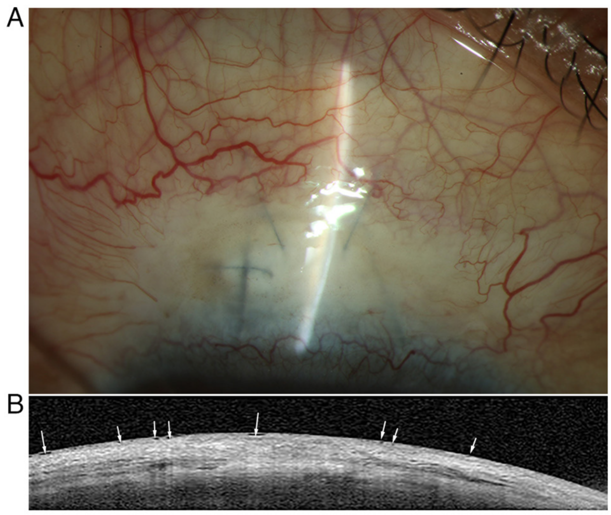

Figure 3. Anterior segment optical coherence tomography-assisted WBCS evaluation of filtering blebs. (A) Bleb photograph and (B) optical coherence tomography scan of a patient (female; age, 62 years) at postoperative month 6. Arrows indicate microcysts. WBCS score: Vascularity, 2; corkscrew vessels, 3; encapsulation, 3; and microcysts, 3. WBCS, Wuerzburg bleb classification system.

found a significant difference in microcysts scores (P<0.001) and a subsequent Nemenyi test found differences between POW 2 and POM 3 (P=0.034) and POM 12 (P=0.05), respectively.

IOP. The lowest IOP during 1 year following surgery was 13.4±4.9 mmHg at POW 2. Subsequently, the IOP gradually increased to 14.5±4.6 mmHg at POM 1 and 18.0±4.2 mmHg at POM 2, before becoming more stable with 17.7±5.1 mmHg at POM 3, 17.6±4.5 mmHg at POM 6 and 17.1±4.5 mmHg at the end of the study period. The IOP at the six postoperative follow-ups was significantly decreased compared with the preoperative IOP (P<0.001). Among the six postoperative visits, significant differences were found between POW 2 and POM 2 (P=0.001), POM 3 (P=0.024) and POM 6 (P=0.013), as well as between POM 1 and POM 2 (P=0.003) (Fig. 6).

Correlation of WBCS scores and IOP. The correlation between the WBCS (total scores and scores of single parameters) and IOP at each visit was analyzed. Negative correlations between total scores and IOP at each visit (r<-0.4; P<0.05), except at POW 2, were found. Among the four single parameters, the microcysts score correlated with the IOP at each visit except POW 2. The correlation was strongest at the final visit (r=-0.640; P<0.001). The vascularity score negatively

Table II. Demographic data and preoperative information of the patients (n=32).

Characteristic	Value
Sex	
Male	9 (28.1)
Female	23 (71.9)
Age, years	59 (53.5, 63.2)
Diagnosis	
Primary open-angle glaucoma	14 (43.8)
Primary angle-closure glaucoma	18 (56.2)
No. of topical glaucoma medications	2 (2, 3)
Preoperative examination	
BCVA, decimal	0.7±0.3
IOP, mmHg	35.9±11.6
Visual field mean deviation, dB	-17.3±9.0
DDLS	5 (4.25, 6.75)
ARNFL thickness, μm	65 (60, 85)

Values are expressed as the median (interquartile range), mean ± standard deviation or n (%). BCVA, best-corrected visual acuity; IOP, intraocular pressure; DDLS, disc damage likelihood scale; ARNFL, average retinal nerve fiber layer.

correlated with the IOP at POM 3 (r=-0.433; P=0.013) and POM 6 (r=-0.664; P<0.001). The corkscrew score negatively correlated with IOP at the early visit after surgery (r=-0.378; P=0.033; POW 2). The encapsulation score negatively correlated with IOP at POW 2 (r=-0.413; P=0.019) and POM 3 (r=-0.397; P=0.025) (Table III).

Surgical outcomes and complications. With regards to surgical outcomes, 15/32 (43.8%) patients achieved success, while 17/32 (56.2%) patients failed to meet the success criteria. Among the latter group, 13 patients had an IOP of ≤21 mmHg with medication or bleb needling, three patients had an IOP of >21 mmHg with medication, while one patient had another glaucoma surgery at POM 7 for losing IOP control. As for surgical complications, one patient (3.1%) had branch retinal vein occlusion and macular edema at 6 months following surgery. Temporary exudative choroiditis occurred in two patients (6.3%). A temporary shallow anterior chamber occurred in one patient (3.1%) (data not shown).

Postoperative antimetabolites and medication. A total of 12 eyes (37.5%) had been treated with bleb needling and subconjunctival injection of 5-FU (0.005 mg/0.2 ml; Jinyao Meditec) once, since signs of encapsulation had been observed. At the final visit, seven eyes (21.9%) received one topical medication and two eyes (6.25%) received two topical medications (data not shown).

Correlations of WBCS with surgical outcomes. The prognostic value of ASOCT-assisted WBCS depends on its correlation with long-term outcomes. Table IV presents the parameters that correlated with such outcomes. The WBCS total score and microcysts score were highly correlated with outcomes (r<-0.4; P<0.05), except at POW 2 and POM 1. The encapsulation score correlated with the outcome at POM 2 and 3. The vascularity score correlated with the outcome at POM 6.

The difference in all parameters between the two outcome groups (success or failure) was measured. Table V presents the parameters that differed significantly between groups (P<0.05). The result was consistent with that of the Spearman analysis and indicated that the WBCS total score and microcysts score were significantly higher in the success group compared with the failure group at POM 2, 3, 6 and 12 (P<0.05). The vascularity score was significantly higher in the success group compared with the failure group at POM 6 (P=0.014) and the encapsulation score was significantly higher in the success group compared with the failure group at POM 2 and 3 (both P=0.025).

Discussion

Since postoperative bleb scarring is the leading cause of trabeculectomy failure (15), appropriate management of blebs, such as the use of anti-inflammation medication, bleb massage, bleb needling or subconjunctival injection of antimetabolites at the early stage of fibrosis, is necessary (14,16,17). It is a challenge for ophthalmologists to find an objective, effective and quick tool to assess the blebs within a limited outpatient follow-up time to predict subsequent problems and long-term effects, which would help guide the subsequent management.

A number of studies have employed MBGS and IBAGS for bleb evaluation (4,6,18). MBGS grades blebs based on the severity of vascularity, bleb wall thickness, height, diffusion and width, with each parameter being scored from 1-10 (6). IBAGS is very simple to assess blebs in terms of bleb height, extent, vascularity and the Seidel test, with each item being graded from 1-4 (4). However, neither system evaluates microcysts (10), which have been proven to correlate with a lower IOP (18). Hereafter, Hoffmann *et al* (7) developed the MaBAGS classification, which involves the grading of microcysts. Contrary to expectation, they found a low level of interobserver agreement for the grading of microcysts. Previous studies have found WBCS is practical in the clinic and suitable for immediate bleb evaluation under the slit-lamp or from photography (3,8,9,14). However, it is difficult to grade encapsulation and microcysts without obtaining enough internal bleb information.

Ultrasound biomicroscopy was first used to evaluate the internal bleb, but it is time-consuming and may cause infection (19). ASOCT has been preferred due to its high-resolution images and cross-sectional scanning mode, which provide detailed insight into the inner structure of the bleb (11,20-23). In spite of several studies committed to developing standard classifications of blebs based on ASOCT images, blebs with mixed morphologies remain challenging to classify. Therefore, more studies focused on combining the ASOCT and classical grading systems from different perspectives are required. Oh *et al* (24) investigated blebs with IBAGS and ASOCT and found that a higher/bulged bleb may indicate a lower IOP. Wen *et al* (25) found that ASOCT and MBGS grades of vascularity are correlated.

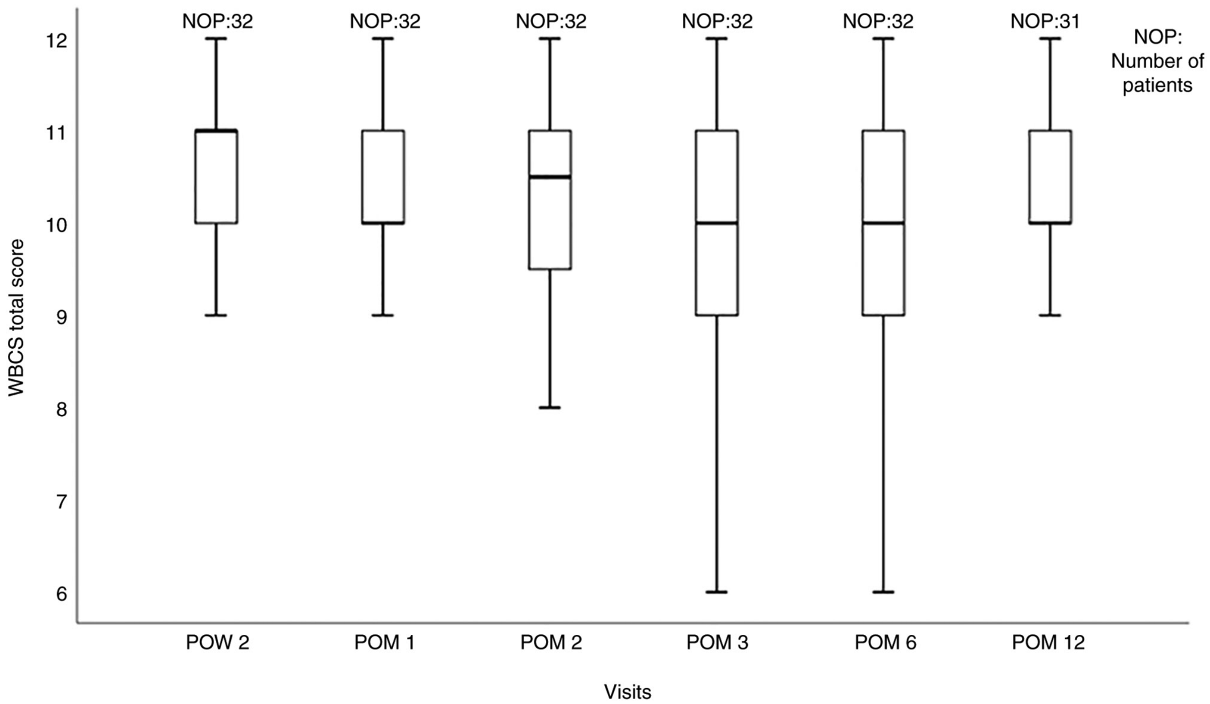

Figure 4. Box-and-whiskers diagram of WBCS total scores over 12 months (boxes indicate the IQR of the WBCS total score; horizontal lines denote the median of the WBCS total score and bars the 1.5xIQR of the WBCS total score). WBCS, Wuerzburg bleb classification system; POW, postoperative week; POM, postoperative month; NOP, number of patients; IQR, interquartile range.

In the present study, ASOCT was adopted for WBCS assessment, since ASOCT may ideally help to grade two critical parameters, namely encapsulation and microcysts. The grading result was hypothesized to be more accurate and objective, and thus better correlated with clinical outcomes, such as IOP.

The present results indicated that the WBCS total scores negatively correlated with IOP at each visit, except POW 2, which is similar to the results reported by Thatte *et al* (9). The correlation became stronger over the course of the 1-year follow-up. Furthermore, compared with previous cross-sectional and retrospective studies (3,8,9), the findings of the present study indicated a stronger correlation between WBCS and IOP.

The WBCS total score was good at POW 2, with the median >10 points and also highest among all visits. The total score decreased at POM 1 and then increased at POM 2. The natural process of bleb formation may explain this trend (26,27). It was observed in the present study that it takes an average time of 1-2 months for a mature bleb to form. The initial bleb morphology was mostly diffused and transparent, leading to better scores in the early postoperative inflammation phase. When the fibrosis started to develop in the proliferative phase, the scores decreased due to increased vascularity and encapsulation. For instance, at POM 1, six patients with increased bleb vascularity were identified and several patients exhibited varying degrees of bleb encapsulation. This may result in lower WBCS total scores. The intervention that included bleb needling or modified medicine following POM 1 may have contributed to the improvement of scores at POM 2. The morphologic change of blebs became slower compared with the previous state when the extended remodeling phase gradually began, which may be why the total scores stabilized following POM 3. In a prior study conducted by Klink *et al* (8), the WBCS total score at 1 year was 9.8±1.3 in the success group and 9.3±1.4 in the failure group. It may be hypothesized that in the present study, ASOCT increased the accuracy of WBCS and may have helped to obtain a higher score. Although the median of the total score was ~10 over time, significant differences were found between the two outcome groups at POM 2, 3, 6 and 12. A significant correlation between WBCS total scores and outcomes at POM 2, 3, 6 and 12 was also found, suggesting that a higher score may indicate a tendency for an improved long-term prognosis. The agreements of the aforementioned two statistical methods suggested that the WBCS total score of POM 2 and the subsequent visits may predict long-term surgical outcomes. A higher score may be associated with better outcome.

Furthermore, a correlation analysis was performed on single parameters of WBCS with IOP and surgical outcomes, and it was explored whether any of them may be potential 'keys' for outcome prediction. The correlation between microcysts and IOP at both early and late postoperative stages (POM 1, 2, 3, 6 and 12) was significant, suggesting that patients with more microcysts had lower IOP. This finding is consistent with previous reports (3,18,28,29). The difference in microcysts scores between the two outcome groups at POM 2, 3, 6 and 12 was significant, and was also highly correlated with surgical outcomes at these time-points (r<-0.4; P<0.05). Therefore, it was concluded that the detection of more microcysts at POM 2 and POM 3, 6 and 12 at the following visits may imply a higher tendency of the long-term success of TRAB and *vice versa*. The microcysts scores were high at the early stage, then decreased after POM 2 and

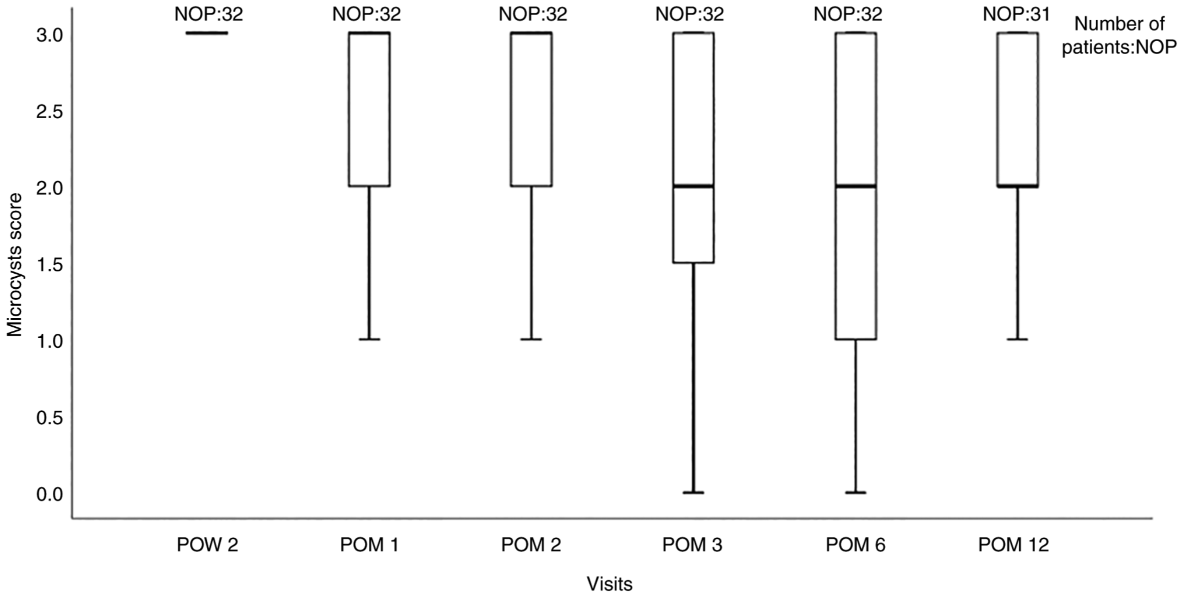

Figure 5. Box-and-whiskers diagram of microcysts scores over 12 months (boxes indicate the IQR of microcysts scores, horizontal lines the microcysts scores and bars the 1.5xIQR of microcysts scores). POW, postoperative week; POM, postoperative month; NOP, number of patients; IQR, interquartile range.

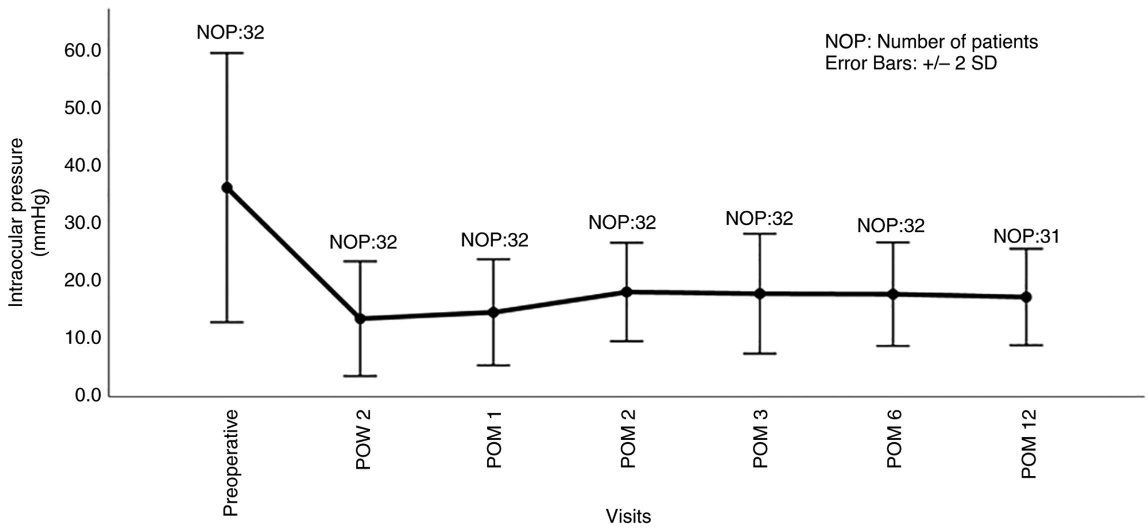

Figure 6. Diagram of preoperative and postoperative IOP. Values are expressed as the mean IOP ± standard deviation. IOP, intraocular pressure; POW, postoperative week; POM, postoperative month; NOP, number of patients; SD, standard deviation.

became stable after POM 3. This finding differs from that of Klink *et al* (8), who found that the microcysts score was lowest following surgery, increased until POM 6 and then declined until POM 12. On the other hand, Kumaran *et al* (18) discovered that the percentage of patients with microcysts peaked at week 6 for eyes treated with 5-FU, similarly to the observation of the present study. According to earlier studies, the presence of microcysts implies aqueous drainage beneath the conjunctiva, suggesting a lower IOP (18,28). The results of the present study support this theory. The decline of the microcysts score from POW 2 to POM 3 and subsequent visits was mostly in line with the rise of IOP from POW 2 to POM 3. The current findings implied that ASOCT may allow for better observation of microcysts than the traditional examination method.

Congestion of the bleb area and growth of corkscrew vessels (4,6,18,29) represent the aggravation of vascularity, indicating the possibility of TRAB failure. OCT angiography also demonstrated the increase of vessel density during bleb fibrosis (20). To ensure the objectivity of vascularity assessment, patients with acute angle-closure or secondary glaucoma, and patients who had previous laser treatment or intraocular surgery, were excluded. In addition, prostaglandin analogue drops were ceased ≥3 days prior to surgery, since they may incite conjunctival inflammation and adversely affect the outcome. The association of bleb vascularity and IOP was investigated and significant correlations at POM 3 and 6 were found. Similarly, Wen *et al* (25) compared the ASOCT bleb grading system with MBGS and found a worse ASOCT bleb grade to be correlated with a high

Table III. Wuerzburg bleb classification system scores that correlated with intraocular pressure.

Follow-up time/parameter	*r*	P-value
POW 2		
Corkscrew vessels	-0.378	0.033
Encapsulation	-0.413	0.019
POM 1		
Total score	-0.451	0.010
Microcysts	-0.364	0.040
POM 2		
Total score	-0.502	0.003
Microcysts	-0.410	0.020
POM 3		
Total score	-0.642	<0.001
Vascularity	-0.433	0.013
Encapsulation	-0.397	0.025
Microcysts	-0.554	0.001
POM 6		
Total score	-0.628	<0.001
Vascularity	-0.664	<0.001
Microcysts	-0.488	0.005
POM 12		
Total score	-0.726	<0.001
Microcysts	-0.640	<0.001

r, Spearman's correlation coefficient; POW, postoperative week; POM, postoperative month.

Table IV. Wuerzburg bleb classification system scores that correlated with outcomes.

Follow-up time/parameter	*r*	P-value
POM 2		
Total score	-0.630	<0.001
Encapsulation	-0.403	<0.001
Microcysts	-0.592	<0.001
POM 3		
Total score	-0.500	0.004
Encapsulation	-0.403	0.022
Microcysts	-0.586	<0.001
POM 6		
Total score	-0.663	<0.001
Vascularity	-0.443	<0.001
Microcysts	-0.664	<0.001
POM 12		
Total score	-0.488	0.005
Microcysts	-0.415	0.020

r, Spearman's correlation coefficient; POM, postoperative month.

IOP at POM 4 and 6, though the correlation was no longer significant at POM 12. Regarding the relationship between vascularity and long-term surgical outcome, Klink *et al* (8) reported that the complete success group in their study had a higher score for vascularity parameters compared with that of the qualified success group and failure group. In the present study, only the score of vascularity at POM 6 was found to significantly correlate with surgical outcomes and differ significantly between the two outcome groups. One explanation of the above fair correlation is that WBCS may not have sufficient sensitivity to reveal a minimal change of vascularity over time. Compared with MBGS, WBCS does not evaluate the vascularity in different bleb areas, and thus, it may not be able to detect the early vascularization in the bleb edge, which leads to a relatively higher (better) score at the early stage.

Certain eyes developed typical corkscrew vessels (CS) in the present study. In a previous study, Klink *et al* (8) found no significant difference in CS between any two postoperative follow-ups within 1 year, while Furrer *et al* (3) found poor agreement between IOP and CS. The present study only found that the correlation between CS and IOP is significant at an early stage (POW 2) and no difference was found among six follow-ups. In a previous study conducted by Sacu *et al* (29), eyes with CS had a higher risk of encapsulation. They suggested that the development of CS may be due to the contraction of fibrous subconjunctival tissue. The current study found CS in three eyes in the first 2 weeks, and one or two eyes at POM 2, 3, 6 and 12. Most of these eyes were found to have encapsulation at the same time, which supports the speculation of Sacu *et al* (29). Although the current findings suggest that more CS may be associated with a higher IOP in the early stages, no further evidence of its prognostic value for long-term outcomes was found.

Encapsulation was considered to be a significant parameter that may indicate late bleb failure. A correlation between encapsulation and IOP at POW 2 and POM 3 was found. This was consistent with previous studies (8,11). More serious encapsulation was associated with a higher IOP. It was also found that encapsulation at POM 2 and 3 was associated with worse surgical outcomes.

In addition, the encapsulation score at POM 2 and 3 was significantly lower in the success group (P<0.05). No correlation was observed after POM 3. This may be explained by the formation process of the encapsulated bleb, which was typically from POW 2 to POM 2 following TRAB. The non-contractile collagen-producing fibroblasts are the major component in the encapsulation process (30). Although the literature suggests that 5-FU is able to inhibit bleb scarring, it cannot inhibit encapsulation (30). In the present study, patients with encapsulation treated with bleb needling and subconjunctival injection of 5-FU obtained improved encapsulation scores at the next visit.

In sum, the present study demonstrated that ASOCT-assisted WBCS is a simple and effective measurement of blebs in clinical practice. It has a good correlation with IOP except in the very early postoperative phase (within 1 month) and is well correlated with surgical outcomes. Among the four single parameters, microcysts correlated best with surgical outcomes, and microcysts score may have the potential to predict future outcomes as early as POM 2. One limitation of

Table V. Comparison of WBCS scores between the two outcome groups.

A, WBCS total score

	Median (interquartile range)		
Follow-up time	Success group	Failure group	P-value
POW 2	11 (10, 11)	11 (10.5, 11)	0.772
POM 1	11 (10, 11)	10 (9.5, 11)	0.059
POM 2	11 (11, 12)	10 (9, 10)	<0.001
POM 3	11 (10, 11)	9 (7.5, 10.5)	0.005
POM 6	11 (10, 12)	9 (8, 10.5)	<0.001
POM 12	11 (10, 11)	10 (9, 10.75)	0.008

B, WBCS vascularity score

	Median (interquartile range)		
Follow-up time	Success group	Failure group	P-value
POW 2	2 (2, 3)	2 (2, 2.5)	0.674
POM 1	2 (2, 3)	2 (1.5, 3)	1.000
POM 2	2 (2, 3)	2 (1, 3)	0.348
POM 3	2 (2, 3)	2 (1, 3)	0.641
POM 6	2 (2, 3)	2 (1, 2)	0.014
POM 12	2 (2, 3)	2 (2, 2)	0.261

C, WBCS encapsulation score

	Median (interquartile range)		
Follow-up time	Success group	Failure group	P-value
POW 2	3 (3, 3)	3 (3, 3)	0.177
POM 1	3 (3, 3)	3 (2.5, 3)	0.188
POM 2	3 (3, 3)	3 (2, 3)	0.025
POM 3	3 (3, 3)	3 (2, 3)	0.025
POM 6	3 (3, 3)	3 (3, 3)	0.093
POM 12	3 (3, 3)	3 (3, 3)	0.333

D, WBCS microcysts score

	Median (interquartile range)		
Follow-up time	Success group	Failure group	P-value
POW 2	3 (2, 3)	3 (3, 3)	0.173
POM 1	3 (2, 3)	2 (2, 3)	0.197
POM 2	3 (3, 3)	2 (1, 3)	0.001
POM 3	3 (2, 3)	2 (1, 2)	0.001
POM 6	3 (2, 3)	1 (1, 2)	<0.001
POM 12	2 (2, 3)	2 (1, 2)	0.023

WBCS, Wuerzburg bleb classification system; POW, postoperative week; POM, postoperative month.

the present study is the relatively small sample size. Besides, the interobserver agreement of ASOCT-assisted WBCS was not evaluated. Further research is needed to ascertain the present conclusion.

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Availability of data and materials

The datasets generated and/or analyzed during the current study are not publicly available due to them containing information that may compromise the privacy of research participants, but are available from the corresponding author on reasonable request.

Authors' contributions

JG performed the surgeries, designed and supervised the study, provided critical revision of the manuscript and followed up patients. YS participated in designing the study, patient recruitment, data acquisition, preparation of the manuscript and patient follow-up. JZ participated in patient recruitment, data acquisition and patient follow-up. YH participated in the data acquisition and interpretation of the image data. ZW contributed to the design of the study and provided critical revision of the manuscript. JG and YS confirm the authenticity of the raw data. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

The research adhered to the tenets of The Declaration of Helsinki and the protocol was approved by the Ethical and Research Committee of The Third People's Hospital of Chengdu (Chengdu, China; grant no. 2021-S-167). Written informed consent was provided by each patient.

Patient consent for publication

Consent for publication was obtained from the patients whose images were included in this article.

Competing interests

The authors declare that they have no competing interests.

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