



# MORPHOLOGY OF TRABECULECTOMY BLEBS USING ANTERIOR SEGMENT OPTICAL COHERENCE TOMOGRAPHY AND RELATION WITH THE CONTROL OF INTRA OCULAR PRESSURE

## Ophthalmology

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## ABSTRACT

**Background:** Trabeculectomy success depends on formation and sustained function of a filtering bleb. Slit-lamp examination provides surface information but does not adequately demonstrate internal bleb architecture. Anterior segment optical coherence tomography (AS-OCT) permits non-contact, high-resolution visualization of internal bleb structures. **Purpose:** To characterize trabeculectomy bleb morphology using AS-OCT and assess its relation with postoperative intraocular pressure (IOP) control/bleb function. **Methods:** This hospital-based analytical study included 50 patients with primary glaucoma aged >35 years who underwent trabeculectomy. IOP was assessed on postoperative days 1, 3, 7 and 15 and at 1 and 3 months. At 1 month, bleb morphology was evaluated with standardized radial and tangential AS-OCT scans. Bleb walls were classified as uniform or multiform reflectivity, with multiform blebs further categorized according to microcysts, subconjunctival separation and multiple internal layers. **Results:** Mean age was  $56.2 \pm 11.01$  years. Mean IOP decreased from  $32.5 \pm 7.56$  mmHg preoperatively to  $11.7 \pm 4.52$  mmHg on day 1 and remained approximately 13–14 mmHg through 3 months. At 1 month, multiform reflectivity with microcysts and multiple internal layers was the most common morphology (50%). Overall, 37 patients (74%) had successful bleb function and 13 (26%) had failure. Multiform morphology with microcysts and multiple internal layers ( $p=0.008$ ) and microcysts plus subconjunctival separation ( $p=0.035$ ) were significantly associated with successful bleb function at 3 months. **Conclusion:** AS-OCT demonstrates clinically relevant internal bleb patterns after trabeculectomy. Multiform blebs containing microcysts with multiple internal layers or subconjunctival separation were associated with better subsequent bleb function and may serve as useful early morphological markers of surgical success.

## KEYWORDS

Trabeculectomy; Filtering Bleb; Anterior Segment Optical Coherence Tomography; Glaucoma; Intraocular Pressure; Bleb Morphology

## INTRODUCTION

Glaucoma is a chronic progressive optic neuropathy and an important cause of irreversible visual impairment. Elevated intraocular pressure (IOP) remains the principal modifiable risk factor and an important therapeutic target in glaucoma management.<sup>[1-3]</sup> When medical and laser treatment are insufficient to achieve target IOP, trabeculectomy remains an established filtration procedure. The long-term success of trabeculectomy depends substantially on formation and maintenance of a functioning subconjunctival filtering bleb. Conventional slit-lamp examination and established grading systems provide useful information regarding bleb height, vascularity, extent and surface appearance, but do not directly visualize the internal architecture that facilitates aqueous filtration.<sup>[4,8]</sup> AS-OCT provides high-resolution cross-sectional imaging of the conjunctiva, scleral flap and internal bleb spaces. Hyporeflective spaces, microcysts, multilayered structures and subconjunctival separation can be demonstrated non-invasively and may provide information about the functional state of the filtration pathway.<sup>[5-10]</sup> Previous studies have reported associations between multiform internal reflectivity, microcysts and multilayered structures and favorable bleb function. Conversely, uniform or highly reflective bleb walls have been associated with poorer filtration in several series.<sup>[4-7,9,10]</sup> The present study evaluated trabeculectomy bleb morphology at 1 month using AS-OCT and examined its relationship with postoperative IOP control at 3 months.

## METHODS

### Study Design and Participants

This hospital-based analytical study was conducted in the Upgraded Department of Ophthalmology, Jawaharlal Nehru Medical College and Associated Group of Hospitals, Ajmer, Rajasthan, India, from March 2024 to March 2025. Ethics committee approval and that written informed consent was obtained from all enrolled participants.

Eligible participants were diagnosed cases of primary glaucoma aged >35 years who provided written informed consent. Exclusion criteria were previous intraocular surgery, congenital or secondary glaucoma, and significant ocular trauma. Sample size was calculated at 95% confidence and 80% power using an expected functional bleb proportion of 89%; 44 cases were calculated and the final sample was rounded to 50.

### Baseline Assessment

Baseline assessment included demographic and clinical history, best-corrected visual acuity, IOP measurement, slit-lamp examination, gonioscopy, central corneal thickness, fundus examination, visual-field assessment and optic-disc/RNFL evaluation by OCT, with other investigations as clinically indicated.

### Trabeculectomy and Follow-up

All surgeries were performed by a single surgeon under local anesthesia. A fornix-based conjunctival flap was created, followed by application of mitomycin C (200 µg) beneath the conjunctiva for 2 minutes. A partial-thickness triangular scleral flap and approximately 2 × 2 mm sclerostomy were fashioned. The scleral flap was secured with two permanent side sutures and one apical releasable 10-0 nylon suture, and the conjunctiva was closed with 10-0 nylon. Antibiotic and steroid drops were prescribed postoperatively in tapering doses over two months.

Follow-up visits were scheduled on postoperative days 1, 3, 7 and 15 and at 1 and 3 months. IOP was measured with Goldmann applanation tonometry. Bleb morphology was evaluated by AS-OCT at 1 and 3 months.

### AS-OCT Assessment

At 1 month, standardized slit-lamp photographs and AS-OCT images were obtained. Patients looked downward while the upper eyelid was gently elevated without applying pressure. Radial and tangential scans were obtained through the point of maximum bleb elevation. A single experienced observer blinded to clinical findings assessed the images.

Bleb walls were classified as uniform or multiform reflectivity. Uniform reflectivity was characterized by a smooth hyperreflective wall without visible hyporeflective fluid-filled spaces. Multiform reflectivity was characterized by hyporeflective spaces within the conjunctiva or bleb wall. Multiform blebs were further categorized according to microcysts, subconjunctival separation and multiple internal layers.

### Statistical Analysis

Qualitative variables were expressed as frequencies and percentages and quantitative variables as mean ± standard deviation. Chi-square testing was used for proportions and Student's t-test for means.

Analyses were performed using SPSS version 26 and Primer. A p value <0.05 was considered statistically significant.

Ethics Statement

Ethics committee approval was brought from the institutional research review board and ethic committee (no. 2429/Acad-III/MCA/2023) of Jawaharlal Nehru Medical College, Ajmer.

RESULTS

Fifty participants were included. Mean age was 56.2 ± 11.01 years. Twenty-eight participants were male (56%) and 22 were female (44%). Right and left eyes were equally represented. Primary open-angle glaucoma accounted for 29 cases (58%) and primary angle-closure glaucoma for 21 (42%).

Table 1. Baseline Demographic and Clinical Characteristics.

| Characteristic  | n  | %  |
|-----------------|----|----|
| Age 35–45 years | 8  | 16 |
| Age 46–55 years | 20 | 40 |
| Age 56–65 years | 8  | 16 |
| Age 66–75 years | 12 | 24 |
| Age >75 years   | 2  | 4  |
| Male            | 28 | 56 |
| Female          | 22 | 44 |
| Right eye       | 25 | 50 |
| Left eye        | 25 | 50 |
| POAG            | 29 | 58 |
| PACG            | 21 | 42 |

Postoperative IOP

Mean preoperative IOP was 32.5 ± 7.56 mmHg. It fell to 11.7 ± 4.52 mmHg on day 1 and remained between 12.85 and 13.6 mmHg through 3 months. The reduction from preoperative IOP to day 1 was statistically significant (paired t=18.5, p<0.001).

Table 2. Mean IOP at Baseline and During Postoperative Follow-up.

| Time point   | Mean IOP (mmHg) | SD   |
|--------------|-----------------|------|
| Preoperative | 32.50           | 7.56 |
| Day 1        | 11.70           | 4.52 |
| Day 7        | 12.85           | 5.77 |
| Day 15       | 13.50           | 6.34 |
| 1 month      | 13.60           | 6.40 |
| 3 months     | 13.50           | 7.06 |

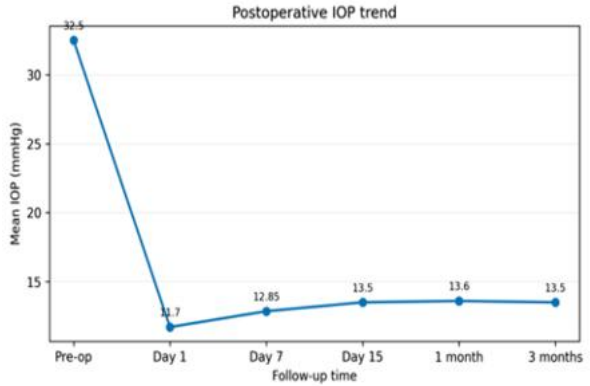


Figure 1. Mean IOP Trajectory Following Trabeculectomy.

AS-OCT Bleb Morphology

At 1 month, multiform reflectivity with microcysts and multiple internal layers was the most common morphology (25 patients, 50%). Multiform reflectivity with only microcysts occurred in 9 (18%), uniform reflectivity in 10 (20%), and microcysts with subconjunctival separation in 6 (12%).

Table 3. AS-OCT Bleb Morphology at 1 Month.

| Bleb morphology                                     | n  | %  |
|-----------------------------------------------------|----|----|
| Multiform + microcysts + multiple internal layers   | 25 | 50 |
| Multiform + microcysts + subconjunctival separation | 6  | 12 |
| Multiform + microcysts alone                        | 9  | 18 |
| Uniform reflectivity                                | 10 | 20 |

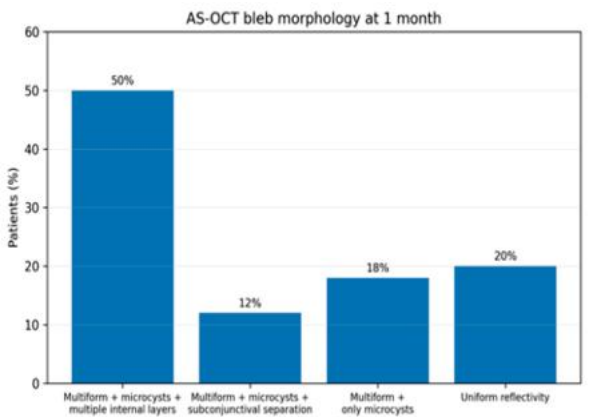


Figure 2. Distribution of AS-OCT Bleb Morphology at 1 Month.

Bleb Function at 3 Months

At 3 months, 37 of 50 patients (74%) were categorized as having successful bleb function and 13 (26%) as bleb failures.

Table 4. Bleb Function at 3 Months.

| Bleb outcome    | n  | %  |
|-----------------|----|----|
| Successful bleb | 37 | 74 |
| Bleb failure    | 13 | 26 |

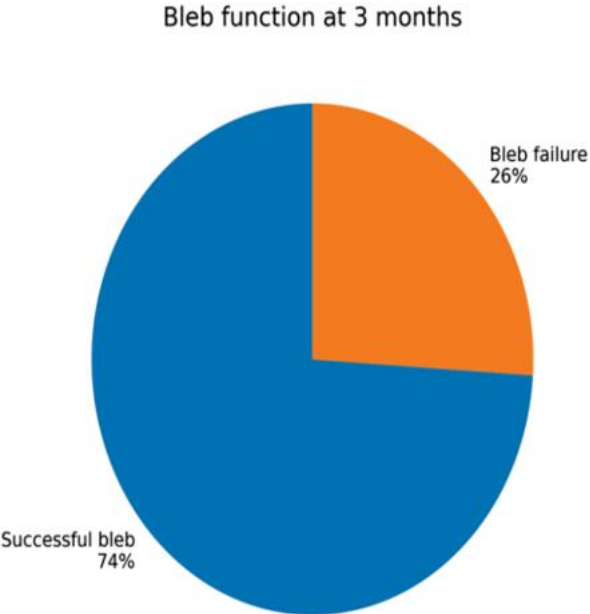


Figure 3. Proportion of Successful and Failed Blebs at 3 Months.

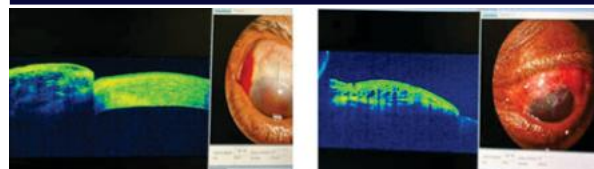
Association Between Early Morphology and Subsequent Bleb Function

Multiform reflectivity with microcysts and multiple internal layers was significantly associated with successful IOP control at 3 months (p=0.008). Multiform reflectivity with microcysts and subconjunctival separation was also significantly associated with success (p=0.035). Associations were not statistically significant for multiform reflectivity with only microcysts (p=0.168) or uniform reflectivity (p=0.739).

Table 5. Association Between 1-month AS-OCT Bleb Morphology and 3-month Bleb Function.

| 1-month AS-OCT morphology                           | Success  | Failure | p value |
|-----------------------------------------------------|----------|---------|---------|
| Multiform + microcysts + multiple internal layers   | 20 (40%) | 5 (10%) | 0.008   |
| Multiform + microcysts + subconjunctival separation | 6 (12%)  | 0 (0%)  | 0.035   |
| Multiform + microcysts alone                        | 7 (14%)  | 2 (4%)  | 0.168   |
| Uniform reflectivity                                | 4 (8%)   | 6 (12%) | 0.739   |
| Total                                               | 37       | 13      | —       |

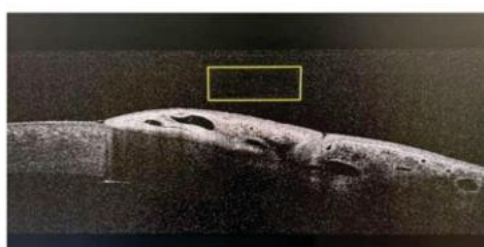
Representative AS-OCT Images



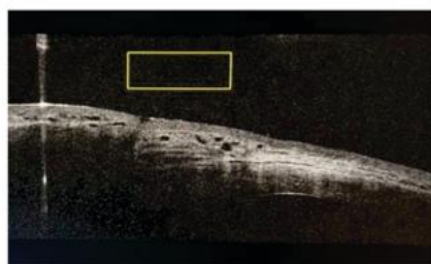
**A) Uniform Reflectivity** **B) Multiform Reflectivity**  
**Figure 4. Representative AS-OCT Images Demonstrating Uniform and Multiform Bleb Wall Reflectivity.**



**A Microcyst = subconjunctival separation**



**B Microcyst = multiple internal layers**



**C Microcystation**

**Figure 5. Representative AS-OCT Appearances of Multiform Blebs with Subconjunctival Separation, Multiple Internal Layers and Microcysts.**

## DISCUSSION

The present study evaluated early trabeculectomy bleb morphology using AS-OCT and its relationship with post operative IOP control. The principal findings were a marked reduction in IOP after surgery, predominance of multiform bleb morphology at 1 month, and significant associations between selected multiform patterns and successful bleb function at 3 months.

Mean IOP declined from  $32.5 \pm 7.56$  mmHg preoperatively to  $11.7 \pm 4.52$  mmHg on day 1 and remained approximately 13–14 mmHg thereafter. This pattern is consistent with the established pressure-lowering effect of trabeculectomy and the role of a functioning filtration pathway in maintaining target IOP.<sup>[3,12,15]</sup>

Multiform reflectivity was the predominant AS-OCT pattern. Half of the participants demonstrated microcysts with multiple internal layers. Khamar et al. reported multiform wall reflectivity in 89% of functioning blebs and identified microcysts with multiple layers and microcysts with subconjunctival separation among common multiform patterns.<sup>[4]</sup> Kawana et al. similarly demonstrated internal fluid-filled cavities and microcysts in functioning blebs.<sup>[6]</sup>

The most important observation was the significant association between selected 1-month morphologies and 3-month IOP control. The microcyst-with-multiple-layer pattern was associated with success in 20 of 25 patients (80%;  $p=0.008$ ), while all six patients with

microcysts with subconjunctival separation were categorized as successful ( $p=0.035$ ). Nakano et al. reported that early multiform structures, particularly multiple-layer patterns, were associated with better later bleb function, while uniform reflectivity was associated with poorer function.<sup>[5]</sup>

AS-OCT provides information that is not available from surface inspection alone. Singh et al. demonstrated that AS-OCT can characterize internal bleb features, while Leung et al. showed the utility of OCT in assessing post-trabeculectomy bleb morphology.<sup>[7,9]</sup> More recent studies and a systematic review/meta-analysis continue to support AS-OCT-based assessment of bleb structure and function.<sup>[10,13,14,16]</sup>

Clinically, the findings suggest that internal hyporeflective spaces and multilayered architecture may provide additional information about aqueous movement and the filtration pathway. AS-OCT may therefore complement slit-lamp examination during postoperative surveillance, particularly when external bleb appearance is equivocal.

Limitations include the small single-center sample, convenient sampling, 3-month follow-up, and assessment of AS-OCT images by a single observer. The source thesis also does not provide a detailed operational definition for the 3-month success/failure classification. Larger multicenter studies with longer follow-up and standardized quantitative bleb metrics are warranted.

## CONCLUSION

AS-OCT provides non-invasive visualization of the internal architecture of trabeculectomy blebs and demonstrates distinct morphological patterns after surgery. In this cohort, multiform blebs containing microcysts with multiple internal layers or subconjunctival separation were significantly associated with successful IOP control at 3 months. AS-OCT may therefore serve as a useful adjunct to clinical examination for early postoperative assessment of trabeculectomy blebs.

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