



ORIGINAL ARTICLE

Conjunctiva-scleral thickness over the Ahmed glaucoma valve tube in eyes at clinically suspected risk of tube exposure: Anterior segment optical coherence tomography findings

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ABSTRACT

Purpose: To characterize conjunctiva-scleral thickness over the Ahmed glaucoma valve tube in eyes clinically considered to be at increased risk of tube exposure based on a superficially positioned tube on anterior segment optical coherence tomography, and to explore the association between post-operative follow-up duration and conjunctiva-scleral thickness. **Methods:** This retrospective study included 22 eyes of 21 patients with 23 Ahmed glaucoma valve tubes. One patient contributed both eyes, and another had two Ahmed glaucoma valve tubes in one eye. All eyes had a minimum post-operative follow-up of 6 months and a clinically apparent superficial tube trace on slit-lamp examination. Over-the-tube conjunctiva-scleral thickness and total conjunctiva-scleral thickness were measured at corresponding locations using anterior segment optical coherence tomography. Associations between conjunctiva-scleral thickness measurements and post-operative follow-up duration were evaluated using correlation analysis and generalized estimating equation models to account for clustering. **Results:** The mean age was 56 ± 12 years (range, 38–80 years). Best-corrected visual acuity was 1.00 (range, 0.10–3.00) LogMAR, and intraocular pressure was 16 (range, 7–27) mmHg. The median post-operative follow-up duration was 40 months (range, 6–135 months), and the median CST overlying the tube at its most superficial location was 190 μm (range, 54–552 μm). A modest inverse correlation was observed between post-operative follow-up duration and conjunctiva-scleral thickness overlying the tube ($p = -0.44$, $p = 0.034$). Generalized estimating equation analysis showed a similar association ($p = 0.019$). However, when eyes were categorized according to post-operative follow-up duration (≤ 1 year, 1–5 years, and ≥ 5 years), no statistically significant differences in conjunctiva-scleral thickness measurements were detected among the groups: 273 (79–552), 190 (54–402), and 119 (64–227) μm , respectively ($p = 0.087$). **Conclusion:** In this preselected high-risk cohort, a modest inverse correlation was observed between post-operative follow-up duration and conjunctiva-scleral thickness overlying the tube; however, this association was not consistently demonstrated across analytical approaches and should therefore be considered exploratory. Anterior segment optical coherence tomography allows objective characterization of tissue coverage over the Ahmed glaucoma valve tube. Further prospective studies with larger cohorts and appropriate control groups are warranted to determine the clinical significance of these findings.

KEYWORDS: Glaucoma; Ahmed glaucoma valve; Intraocular pressure; Anterior segment; Optical coherence tomography; Conjunctiva; Scleral thickness

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INTRODUCTION

Glaucoma is the leading cause of irreversible vision loss worldwide. Because the disease is often asymptomatic during its early stages, diagnosis may be delayed⁽¹⁾. Trabeculectomy with mitomycin C and glaucoma drainage devices, including the Ahmed glaucoma valve (AGV), are well-established surgical options for glaucoma management⁽²⁾.

Tube exposure is a significant complication of AGV implantation and typically occurs within 1–2 years after surgery⁽³⁾, with a reported incidence of 2.5% to 8.9%⁽⁴⁾. Exposure of the tube can cause ocular surface inflammation and increase the risk of late-onset endophthalmitis by providing a pathway for microorganisms to enter the anterior chamber⁽⁵⁾.

Anterior segment optical coherence tomography (AS-OCT) has been widely used to assess bleb morphology after AGV implantation^(6,7) and to evaluate graft thinning in eyes receiving pericardial or amniotic membrane patch grafts⁽⁸⁾. A recent study demonstrated progressive thinning of pericardial patch grafts and stromal tissue covering the AGV tube during a 6-month follow-up period⁽⁹⁾. Although AS-OCT has been used to evaluate graft thickness, its role in quantitatively characterizing the conjunctiva-scleral complex over non-grafted, scleral flap-covered tubes remains insufficiently explored. This represents an important gap in the current literature.

Therefore, this study aimed to characterize over-the-tube CST and total CST using AS-OCT in a preselected cohort of eyes considered to be at increased risk of tube exposure and to explore their association with post-operative follow-up duration (PFD).

METHODS

The study was conducted in accordance with the Declaration of Helsinki, and we obtained written informed consent from all participants. The Scientific Research Ethics Committee of our hospital approved the study.

Patients who underwent AGV implantation using the scleral flap technique at the Department of Ophthalmology of our hospital were eligible for inclusion. Among the 156 patients followed in the glaucoma unit between February 2022 and 2024, 21 patients with 22 eyes (23 AGV tubes) and at least 6 months of post-operative follow-up were identified as having a clinically apparent superficial tube trace on slit-lamp biomicroscopy and were referred for AS-OCT evaluation. Superficial tube prominence was defined as a visible tube contour beneath the conjunctiva with minimal overlying tissue coverage on slit-lamp biomicroscopy, suggesting

reduced conjunctival protection and a potential risk of tube exposure. One patient contributed both eyes to the study. In another patient, one eye contained two AGV tubes after implantation of a second AGV in the inferonasal quadrant following failure of the initial superotemporal AGV.

Clinical classification was independently performed by two experienced glaucoma specialists, and inclusion was based on consensus. Because of the retrospective study design, the examiners were not masked to the clinical information, and formal interobserver agreement was not assessed. The area of greatest tube prominence was identified clinically, followed by AS-OCT imaging to obtain objective CST measurements. All AS-OCT measurements were performed by an experienced glaucoma specialist. Because only eyes with clinically suspected superficial tube prominence were included, the study was not designed to compare high- and low-risk eyes or establish CST thresholds predictive of tube exposure.

AS-OCT scans

Over-the-tube CST, defined as the combined thickness of the conjunctiva, Tenon's capsule, and overlying scleral tissue covering the AGV tube, was measured using swept-source AS-OCT (Triton DRI, Topcon, Tokyo, Japan). To localize the area of greatest tube prominence, the most superficial portion of the tube identified on slit-lamp biomicroscopy was marked before imaging (Figure 1). Cross-sectional AS-OCT scans perpendicular to the tube were then obtained (Figure 2). The device provides high-resolution imaging at 100,000 A-scans/s using a 1050-nm wavelength laser and has an imaging depth of 2.6mm⁽¹⁰⁾.

During image acquisition, patients were instructed to look away from the quadrant containing the AGV, while the eyelid was gently elevated to expose the adjacent bulbar conjunctiva. Six-millimeter linear scans were acquired. Minor misalignment between the clinically identified region and the AS-OCT section may have occurred because of eye movement or tissue variability.

Total CST was defined as the combined thickness of the conjunctiva, Tenon's capsule, and adjacent scleral tissue outside the direct tube elevation. The mean of three manual measurements was used for analysis.

Surgical approach

Sub-Tenon's anesthesia was administered to all patients before surgery. The FP7 model of the silicone AGV implant (New World Medical Inc., Rancho Cucamonga, California) was used in all cases. One eye underwent implantation of

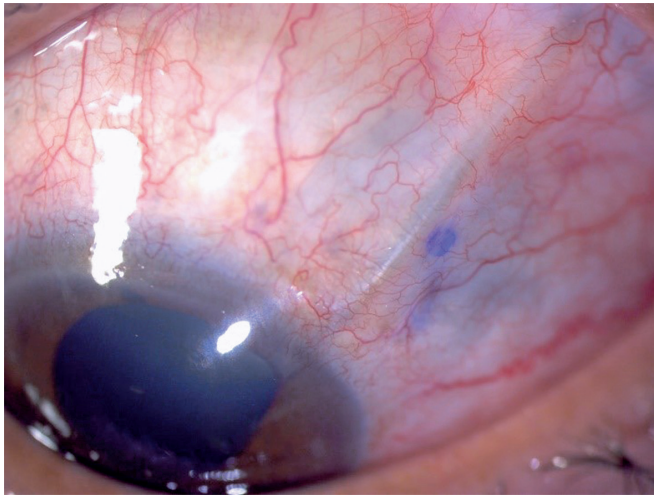


Figure 1. Biomicroscopic anterior segment examination identified the Ahmed Glaucoma Valve tube as the most superficial structure. The conjunctiva-scleral area overlying the tube was then marked with a marker pen.

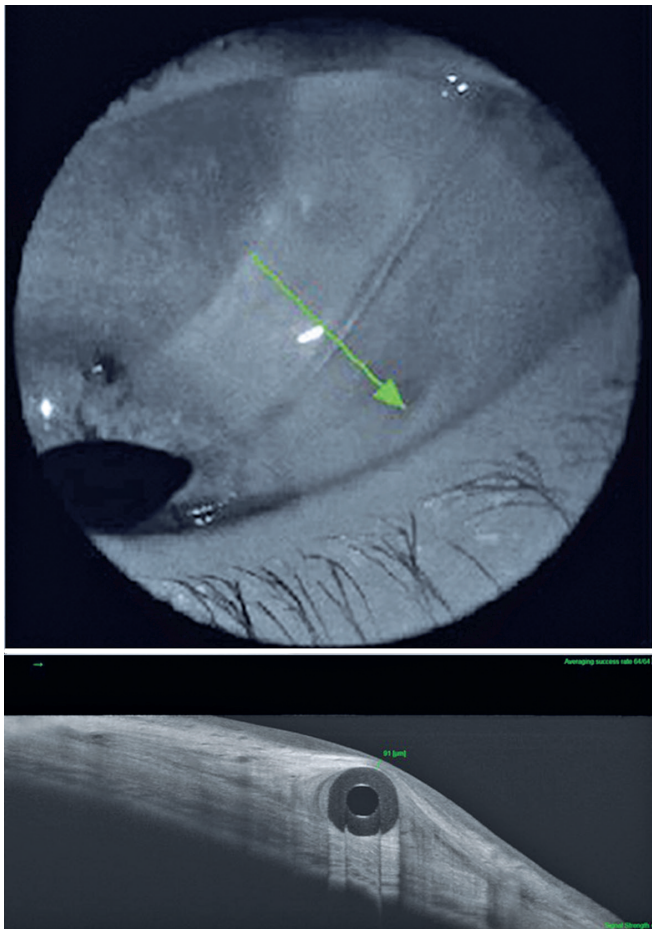


Figure 2. Conjunctiva-scleral thickness overlying the Ahmed glaucoma Valve tube, measured using anterior segment optical coherence tomography

a second AGV in the inferonasal quadrant following failure of the initial superotemporal AGV. In another patient, the AGV was implanted in the inferonasal quadrant because of superior conjunctival scarring.

After an incision was made in the appropriate quadrant for valve placement, a 4 × 5-mm half-thickness, limbus-based scleral flap was created using a fornix-based conjunctival approach. Balanced salt solution was then injected to prime the valve mechanism. The Ahmed valve reservoir was subsequently advanced toward the equator of the globe beneath the conjunctiva and sutured to the sclera with 6-0 Vicryl sutures (Ethicon, New Jersey), 9 mm posterior to the limbus. A 22-gauge needle with a black tip was used to enter the anterior chamber beneath the scleral flap. The tube was angled and trimmed to leave 2–3 mm within the anterior chamber and was then secured in position.

The tube tip was placed in the sulcus in two cases. One of these eyes had extensive 360° synechiae and a history of keratoplasty and graft rejection, whereas the other had peripheral anterior synechiae in the superotemporal region. The scleral flap was sutured with interrupted 10-0 nylon sutures, and a nylon U-suture was used to secure the tube at the scleral flap entry site. Finally, the conjunctiva and Tenon's capsule were closed with continuous 8-0 Vicryl sutures.

None of the eyes had undergone previous glaucoma surgery, and no antimetabolites, such as mitomycin C, were used during surgery. Postoperatively, patients were prescribed topical antibiotics for 2 weeks and topical corticosteroids for 4 weeks.

Post-operative ophthalmologic examination findings, including best-corrected visual acuity (BCVA) measured in logMAR, anterior and posterior segment findings, intraocular pressure (IOP) measured by Goldmann applanation tonometry, and retinal nerve fiber layer thickness measured using the same OCT device, were recorded. Age, sex, glaucoma diagnosis, number of antiglaucoma medications, AGV tube location, AGV tube tip location, and PFD were also recorded. The association between CST measurements and PFD was evaluated.

Statistical analysis

Statistical analyses were performed using SPSS version 24 (IBM SPSS Statistics, Armonk, New York). Data distribution was assessed using the Shapiro-Wilk test. Normally distributed variables are presented as mean±standard deviation, whereas nonnormally distributed variables are presented as median (range) and interquartile range, as appropriate.

The Kruskal–Wallis test was used to compare independent groups. To account for within-patient correlation arising from clustered observations, including bilateral observations from one patient and two AGV tubes in one eye of another patient, generalized estimating equation (GEE) analysis with an exchangeable correlation structure and robust standard errors was used as the primary analytical approach. Correlations were assessed using Spearman's rank correlation test, and linear regression analyses were performed when appropriate. Intraobserver repeatability was assessed using intraclass correlation coefficients (ICCs) and coefficients of variation (CVs). A *p* value <0.05 was considered statistically significant.

RESULTS

Twenty-one patients (22 eyes; 9 men and 12 women) with a mean age of 56±12 years (range, 38–80 years) were included. One patient contributed both eyes, whereas another had two AGV tubes in one eye, resulting in a total of 23 AGV tubes. The second AGV in the same eye was implanted in the inferonasal quadrant following failure of the initial superotemporal AGV. The median BCVA was 1.00 logMAR (range, 0.10–3.00), the median postoperative IOP was 16mmHg (range, 7–27mmHg), and the median follow-up duration was 40 months (range, 6–135 months). Most eyes were pseudophakic. Indications for AGV implantation included primary open-angle glaucoma, pseudoexfoliative glaucoma (PEXG), neovascular glaucoma (NVG), silicone oil-induced glaucoma, post-penetrating keratoplasty glaucoma, and uveitic glaucoma (Table 1).

When patients were categorized according to PFD (≤1 year, 1–5 years, and >5 years), over-the-tube CST tended to be thinner with longer PFD; however, the differences in over-the-tube CST and total CST were not statistically significant (*p*=0.087 and *p*=0.264, respectively; Table 2). Spearman rank correlation analysis demonstrated a modest inverse correlation between PFD (median, 40 months [range, 6–135 months]) and over-the-tube CST (median, 190 μm [range, 54–552 μm]; *p*=–0.44, *p*=0.034). In contrast, total CST was not significantly correlated with PFD (*p*=0.275). Simple linear regression did not demonstrate a statistically significant association between PFD and over-the-tube CST (β =–1.25, 95% CI, –2.63 to 0.13; *p*=0.074).

When eyes were categorized according to IOP (≤15mmHg, 16–21mmHg, and ≥22mmHg), neither over-the-tube CST nor total CST differed significantly among the groups (*p*=0.490 and *p*=0.156, respectively; Table 3). In the GEE analysis, PFD was significantly associated with over-the-tube CST. Compared with the reference category, eyes in the longer

Table 1. Demographic characteristics of patients with AGV and clinical data.*

	n (21 patients/22 eyes/23 AGV) [†]
Age (years) [mean ± SD (min–max)]	56 ± 12 (38–80)
Sex (male/female)	9/12
Laterality (right/left)	11/12
BCVA (LogMAR)	1.00 (0.1–3.00), 2.9
CCT (μm)	570 (490–770), 280
IOP (mmHg)	16 (7–27), 20
AGV tube location	
Superotemporal	21
Inferonasal	2
AGV tube tip location	
Anterior chamber	21
Sulcus	2
Lens status	
Phakic	4
Pseudophakic	17
Aphakic	2
Post-operative follow-up duration (month)	40 (6–135), 129
Antiglaucomatous medications (mean±SD)	2.2±1.1
RNFL (μm)	77 (29–111), 82
Glaucoma diagnosis (21 patients)	
Primary open-angle glaucoma	5
Pseudoexfoliation glaucoma	3
Neovascular glaucoma	4
Silicon oil-induced glaucoma	3
Post-penetrating keratoplasty for glaucoma	5
Uveitic glaucoma	1

AGV= Ahmed Glaucoma Valve; BCVA= best-corrected visual acuity; CCT= central corneal thickness; IOP= intraocular pressure; min–max= minimum–maximum; n= number; RNFL= retinal nerve fiber layer; SD= standard deviation.

*Median (min–max), interquartile range.

[†]One eye had two AGV tubes, resulting in a total of 23 AGV tubes in 22 eyes.

follow-up group had significantly lower over-the-tube CST values (β =–58.83 μm, 95% CI, –107.91 to –9.75; *p*=0.019). Categorized IOP levels were not significantly associated with over-the-tube CST (*p*=0.723). When total CST was considered the dependent variable, neither PFD category (*p*=0.074) nor IOP category (*p*=0.339) was significantly associated with CST. Furthermore, IOP was not significantly correlated with either over-the-tube CST or total CST (*p*=0.366 and *p*=0.394, respectively).

In this study, AS-OCT showed that over-the-tube CST represented 27.2%±14.5% of the total CST. Intraobserver repeatability was excellent for both over-the-tube CST (ICC=0.995; CV=3.9%) and total CST (ICC=0.993; CV=0.94%), indicating high measurement reliability and low relative variability.

Table 2. Comparison of conjunctival-scleral thickness measurements on AGV according to postoperative follow-up duration.

CST measurements (μm) (median, [min-max], IQR)	Postoperative follow-up duration			p-value*
	≤ 1 year (n=9)	1-5 years (n=7)	≥ 5 years (n=7)	
Over-the-tube CST	273 (79-552), 473	190 (54-402), 348	119 (64-227), 163	0.087
Total CST	839 (622-927), 305	750 (522-925), 373	776 (589-873), 284	0.264

AGV= Ahmed Glaucoma Valve; CST= conjunctival-scleral thickness; IQR= interquartile range; min-max= minimum-maximum; n= number of AGV.

*Kruskal-Wallis test.

Table 3. Comparison of conjunctiva-scleral thickness measurements on AGV according to IOP.

CST measurements (μm) (median [min-max], IQR)	IOP measurements (mm Hg)			p-value*
	≤ 15 (n=11)	16-21 (n=9)	≥ 22 (n=3)	
Over-the-tube CST	227 (64-402), 338	131 (54-552), 498	169 (104-324), 220	0.49
Total CST	750 (589-875), 286	808 (626-927), 301	737 (522-871), 319	0.156

AGV= Ahmed Glaucoma Valve; CST= conjunctival-scleral thickness measurements; IOP= intraocular pressure; IQR= interquartile range; min-max= minimum-maximum; n= number of AGV.

*Kruskal-Wallis test.

DISCUSSION

In the present study, CST overlying the AGV tube appeared relatively thin in this preselected high-risk cohort, in which superficial tube prominence had already been identified clinically. Although a statistically significant, modest inverse correlation was observed between PFD and over-the-tube CST ($p=-0.44$, $p=0.034$), this association was not confirmed when the data were analyzed according to clinically relevant post-operative time categories (≤ 1 , 1-5, and ≥ 5 years), with no significant differences among groups ($p=0.087$). Furthermore, the association did not reach statistical significance in the linear regression model, and total CST was not associated with the time elapsed since surgery. These findings suggest that any reduction in tissue thickness over the tube may occur gradually rather than as a distinct difference between post-operative intervals. The discrepancy among analytical approaches may reflect the limited sample size and the influence of extreme values. Therefore, the observed association should be interpreted cautiously and cannot be considered evidence of progressive, time-dependent CST thinning. Rather, it should be regarded as exploratory and hypothesis-generating. Clinically, the weak negative correlation may suggest that eyes with longer PFD have thinner CST; however, given the lack of consistency across analyses, this finding cannot currently be used to guide management or predict tube exposure risk.

The AGV is one of the most widely used glaucoma drainage implants worldwide⁽¹¹⁾. Conjunctival erosion over the tube or plate is a potentially serious complication following AGV implantation. A previous study reported a 5.8% exposure rate for glaucoma drainage devices, with a

mean time to exposure of 25.0 ± 21.3 months⁽¹²⁾. Risk factors for exposure include younger age, inflammation, uveitic glaucoma, NVG, inferior device placement, and concomitant procedures, particularly cataract surgery or vitrectomy^(3,13). Various surgical techniques have been developed to reduce the risk of tube exposure, including the use of different graft materials and scleral flaps, although each approach has limitations⁽¹⁴⁾. Tenon advancement or duplication techniques have demonstrated efficacy in preventing tube exposure^(15,16). Techniques involving long scleral tunnels have also shown promise in reducing conjunctival erosion and tube exposure by isolating the tube from the conjunctiva and minimizing trauma caused by tube movement⁽¹⁷⁻¹⁹⁾. More recently, a suture-guided AGV tube implantation technique has been described to improve tube positioning⁽²⁰⁾.

In this context, our study was designed to descriptively characterize CST overlying the tube in eyes already considered clinically to be at increased risk, rather than to validate AS-OCT as a predictive or risk-stratification tool. Because the cohort consisted exclusively of eyes with clinically apparent superficial tube prominence, the findings cannot be generalized to the broader AGV population or used to establish clinically meaningful CST thresholds associated with tube exposure. Moreover, more than half of the eyes ($n=13$) had diagnoses associated with increased conjunctival fragility, including NVG ($n=4$), silicone oil-induced glaucoma ($n=3$), post-penetrating keratoplasty glaucoma ($n=5$), and uveitic glaucoma ($n=1$), which may have contributed to the relatively thin CST measurements.

AS-OCT is a valuable, noninvasive technique for visualizing and quantifying anterior segment structures⁽²¹⁻²³⁾. A recent study reported that, in healthy eyes, the mean conjunctival,

episcleral, and scleral thicknesses at the superior quadrant were 77 ± 16 , 174 ± 54 , and 467 ± 52 μm , respectively, yielding an approximate total thickness of 718 μm ⁽²⁴⁾. However, these normative values represent undisturbed tissues and therefore cannot be directly compared with CST overlying an AGV tube. In the surgical setting, the tissue is altered by conjunctival peritomy, scleral flap dissection, and the mechanical presence of the tube, all of which may reduce its native thickness.

In our study population, the median total CST was 766 μm (range, 552 – 927 μm), which was broadly consistent with published values. In our surgical practice, the AGV tunnel is designed to allow at least half of the total scleral thickness to cover the tube. In this cohort, the median over-the-tube CST was 190 μm (range, 54 – 552 μm), corresponding to $27.2\pm14.5\%$ of the total CST. Although this proportion was relatively small, no immediate tube exposure was observed. The patients were therefore advised to undergo close clinical follow-up, including AS-OCT evaluation.

Few studies have directly evaluated CST overlying an AGV tube using AS-OCT in the context of exposure risk. Previous studies have primarily focused on bleb morphology after AGV implantation^(6,7) or XEN stent placement⁽²⁵⁾. A recent study evaluating pericardial patch grafts demonstrated significant stromal thinning over the central portion of the tube between 1 and 6 months ($p=0.015$), followed by stabilization⁽⁹⁾. Unlike that study, our study did not longitudinally assess the same eyes and therefore cannot establish time-dependent thinning. Longitudinal follow-up might have demonstrated progressive CST reduction within individual eyes. Refractive effects on AS-OCT thickness measurements are generally minimal when repeated measurements are performed in the same eye. In our study, however, most patients were pseudophakic and CST was compared across different PFD categories; therefore, refractive status was not included in the analysis.

The main limitations of this study were its retrospective design and small sample size, which precluded assessment of longitudinal changes in over-the-tube CST within individual patients. Although no control group with deeply positioned AGV tubes was included, over-the-tube CST was compared with each patient's total CST, providing an internal reference. Consequently, the findings cannot determine whether CST progressively decreases over time, whether specific CST values are associated with an increased risk of tube exposure, or whether AS-OCT measurements can distinguish high-risk from low-risk eyes. The absence of a control group with clinically deep-seated tubes further limits interpretation and generalizability. Nevertheless, this pilot

study provides descriptive data from a preselected high-risk cohort and demonstrates that AS-OCT can facilitate detailed visualization and quantification of tissue coverage over the AGV tube. This approach may be useful for structural monitoring of eyes considered clinically at increased risk of tube exposure, including eyes with concomitant surgeries, PEXG, diabetes, or inferior device placement^(13,26). The clinical heterogeneity of the cohort may also have influenced conjunctival characteristics, and potential confounders, including glaucoma diagnosis, tube quadrant, lens status, and previous corneal surgery, could not be adequately adjusted for.

In conclusion, this exploratory analysis of clinically selected eyes demonstrated a modest inverse correlation between PFD and over-the-tube CST. However, the absence of consistent findings across analytical approaches and the limited sample size warrant cautious interpretation. No cases of clinical tube exposure occurred during follow-up; therefore, predictive conclusions regarding exposure risk cannot be drawn. AS-OCT enabled objective structural characterization of CST in eyes with clinically suspected reduced tissue coverage over the tube. These findings should not be interpreted as establishing CST thresholds or predictive markers for tube exposure. Further prospective studies with larger cohorts, longitudinal follow-up, and appropriate comparison groups are needed to clarify the clinical significance of CST measurements and their potential relationship with tube exposure risk.

AUTHORS' CONTRIBUTIONS

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Fatma Isil Sozen-Delil, Raziye Dönmez Gün.

Data analysis and Interpretation:

Fatma Isil Sozen-Delil.

Manuscript drafting:

Fatma Isil Sozen-Delil.

Significant intellectual content revision of the

manuscript: Fatma Isil Sozen-Delil, Raziye Dönmez Gün.

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Fatma Isil Sozen-Delil, Raziye Dönmez Gün.

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support: Fatma Isil Sozen-Delil, Raziye Dönmez Gün.

Research group leadership:

Fatma Isil Sozen-Delil, Raziye Dönmez Gün.

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