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Long-Term Monitoring of Corneal Grafts Via Anterior Segment OCT Pachymetry Maps

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Purpose: To assess the efficacy of anterior segment OCT (AS-OCT) in the long-term monitoring of corneal grafts and its integration into a hybrid remote care model for early detection and management of graft rejection or failure.

Design: Prospective cohort study.

Participants: Seventy-four patients (93 eyes) who underwent corneal transplantation from October 2021 to December 2023, with a follow-up period of ≥6 months.

Methods: Serial AS-OCT pachymetry maps and cross-sectional scans were performed at fixed postoperative intervals, and the findings were correlated with clinical signs of graft rejection or failure on slit lamp examination for thickness changes >50 μm. A hybrid remote AS-OCT screening protocol was initiated 1 week postoperatively.

Main Outcome Measures: Diagnostic accuracy of AS-OCT, measured by specificity and sensitivity, in detecting graft rejection or failure through changes in corneal and graft thickness.

Results: Anterior segment OCT demonstrated high diagnostic accuracy with a specificity of 97.6% and a sensitivity of 88.9% in detecting graft rejection or failure. The mean central corneal thickness increase in cases resulting in graft rejection or failure was 82.7 ± 21.5 μm, a thickness change that is not discernible by slit lamp examination alone. The utility of AS-OCT in a hybrid remote monitoring model was demonstrated through 3 detailed case studies, highlighting improved clinical workflow and patient convenience without compromising postoperative outcomes.

Conclusions: Serial AS-OCT imaging serves as a robust, objective, and quantitative tool for postoperative surveillance of corneal grafts, significantly benefiting patient outcomes by allowing timely interventions. Integration of AS-OCT into a hybrid remote screening protocol supports comprehensive monitoring, complementing direct clinical evaluations and optimizing postoperative care.

Financial Disclosure(s): Proprietary or commercial disclosure may be found in the Footnotes and Disclosures at the end of this article.

Corneal transplantation, including penetrating keratoplasty (PKP) and lamellar techniques such as Descemet stripping automated endothelial keratoplasty (DSAEK) and Descemet membrane endothelial keratoplasty (DMEK), is the most frequently performed transplant procedure worldwide.[1] Despite advances in surgical techniques and postoperative management, graft rejection and failure remain significant challenges, with reported rates of 23% to 35% for PKP, 10% to 12% for DSAEK, and 1% to 3% for DMEK.[2,3] Early detection and appropriate management of graft rejection are crucial for preventing graft failure, which can result from prolonged rejection or occur independently because of endothelial decompensation.

Graft rejection is characterized by an immune response against the transplanted tissue, potentially leading to failure if not promptly and effectively treated. However, graft failure can also occur in the absence of rejection due to endothelial cell loss in aging grafts or due to mechanical factors (e.g., presence of glaucoma drainage device). Distinguishing between rejection and failure in clinical practice is challenging, especially when the graft appears edematous. This edema can obscure the view of the anterior chamber, complicating the assessment of inflammation and other signs of rejection. Therefore, clinicians often initially treat edematous grafts aggressively as potential rejections; if no improvement follows, it is then determined that the underlying issue is more likely graft failure.

Anterior segment OCT (AS-OCT) has emerged as a powerful imaging modality for evaluating the cornea and anterior segment. Anterior segment OCT provides high-resolution cross-sectional images and pachymetry maps that enable objective and quantitative assessment of corneal thickness, graft–host interface, and other anatomic details.[4] Several studies have demonstrated the utility of AS-OCT in the early postoperative period after corneal transplantation, particularly for detecting graft detachments and guiding rebubbling procedures.[5,6] However, the role of AS-OCT in the long-term monitoring of corneal grafts remains less well defined.

This study aims to elucidate the long-term utility of AS-OCT in monitoring corneal grafts and to evaluate its integration into a hybrid screening protocol. This approach aims to enhance remote monitoring capabilities while ensuring

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direct specialist oversight is available when necessary, optimizing both early detection and management of graft complications.

Methods

Study Design and Participants

This prospective cohort study included patients who underwent corneal transplantation (DMEK, DSAEK, or PKP) by a single surgeon (S.P.) between October 2021 and December 2023. Patients with ≥6 months of postoperative follow-up with AS-OCT imaging at predefined intervals were included in the analysis. Patients with <6 months of follow-up were excluded. The study was approved by the institutional review board and adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained by all study participants.

Anterior Segment OCT Imaging Protocol

All patients underwent AS-OCT imaging (Triton; Topcon Healthcare) at the following postoperative time points: day 0, day 1, week 1, month 1, month 3, month 6, month 9, and every 6 months thereafter. Pachymetry maps of the central 6 mm zone were generated, providing corneal thickness measurements across the graft. High-resolution cross-sectional scans were also analyzed for changes in graft thickness using the manual caliper tool available on the OCT software and for the detection of keratic precipitates. These parameters were correlated with clinical signs of graft rejection or failure observed on slit lamp examination should an increase in central corneal thickness (CCT) ≥50 μm from the previous visit scan was observed.

Hybrid Remote Screening Integration

All patients were enrolled in a hybrid screening protocol for remote AS-OCT monitoring after the 1-week postoperative visit. This enrollment marked the beginning of serial assessments rather than setting a fixed baseline CCT for comparison. The screening process involved evaluating the patient's visual acuity, intraocular pressure using the iCare IC100 tonometer (iCare Finland Oy), corneal thickness stability using AS-OCT pachymetry, and the presence of keratic precipitates and graft thickness stability on cross-sectional OCT images.

If the patient's vision and symptoms were stable, corneal and graft thickness remained unchanged on AS-OCT pachymetry and cross-sectional imaging, respectively, and no keratic precipitates were detected on cross-sectional images, the patient was deemed suitable for remote monitoring. However, any deviation from these stable conditions warranted a referral to the attending cornea specialist clinic for further evaluation and management. This approach allowed for dynamic, ongoing evaluation of each patient's postoperative recovery and graft function at each visit without the constraints imposed by an early postoperative baseline CCT, which might be influenced by residual corneal edema. Specifically, compared to the patient's prior visit, any changes in visual acuity ≥1 Snellen line, the onset of new symptoms, an increase in CCT equal to or >50 μm, or the presence of keratic precipitates on AS-OCT triggered a referral to the attending clinic for a comprehensive assessment. The threshold of 50 μm for significant changes in CCT was selected empirically, based on prior clinical observations using AS-OCT for the monitoring of corneal grafts prior to the start of this prospective study. It should be noted that endothelial keratoplasty patients underwent a comprehensive examination by the attending corneal specialist and underwent suture removal from the main wound at 3 months postoperatively. Penetrating keratoplasty patients were examined in detail by the attending corneal specialist at 6 and 12 months, whereby suture removal was performed.

Statistical Analysis

Descriptive statistics were used to summarize patient demographics, graft type, and postoperative outcomes. Sensitivity and specificity of AS-OCT parameters for predicting graft rejection or failure were calculated using slit lamp findings as the gold standard. All statistical analyses were performed using SPSS version 26.0 (IBM Corp.), with a significance level set at $P < 0.05$. The sample size was determined based on an expected sensitivity of 90% and specificity of 85% for AS-OCT in detecting graft failure or rejection, with a precision of 10% and a confidence level of 95%, resulting in a minimum requirement of 50 eyes.

Results

Patient Demographics

The study cohort consisted of 74 patients (93 eyes) who underwent corneal transplantation between October 2021 and December 2023. The mean age of the participants was 71 ± 14 years (range, 20−89 years). The cohort included 41 men (55.4%) and 33 women (44.6%). Of the 93 operated eyes, 24 underwent PKP, whereas 71 underwent endothelial keratoplasty (64 DSAEK, of which 7 were combined with cataract surgery, and 5 DMEK). Eight patients (10.8%) received bilateral grafts and 8 patients (10.8%) underwent repeat grafting because of rejection or failure. Patient demographics are presented in detail in Table 1.

Sensitivity and Specificity of AS-OCT Pachymetry Maps in Detecting Graft Rejection or Failure

In this study, among 93 eyes subjected to DSAEK, 2 cases exhibited significant increases in CCT >50 μm on the AS-OCT pachymetry map between 2 consecutive visits without resulting in graft rejection or failure, thus representing false positives. Conversely, of the 9 cases that culminated in graft rejection or failure, 8 demonstrated an increase in CCT >50 μm, marking them as true positive cases. Additionally, there was 1 case where a decrease in CCT between 2 visits led to graft failure, categorized as a false negative. Overall, 82 of the 93 eyes showed no CCT increase beyond the 50 μm threshold between 2 visits and did not undergo rejection or failure, classifying them as true negatives.

Based on the above, the specificity of AS-OCT pachymetry maps in this context is 97.6%, indicating a high reliability in ruling out graft failure or rejection when no significant CCT increase occurs. Similarly, the sensitivity is 88.9%, reflecting the effectiveness of AS-OCT pachymetry maps at correctly identifying individuals likely to experience graft rejection or failure when an increase in CCT is observed. The average CCT increase in the true positive cases was 82.7 ± 21.5 μm, ranging from 61.2 μm to 104.1 μm. The robust combination of high sensitivity and specificity underscores the reliability of AS-OCT

Table 1. Demographics of Study Participants

n = 74 Patients (93 Eyes)	n	%
Sex		
Female	33	44.6
Male	41	55.4
Preoperative diagnosis		
PBK	31	33.3
Fuchs	33	35.4
Failed graft	21	22.5
Other*	8	8.6
Type of surgery		
DMEK	5	5.4
DSAEK	64	68.8
PKP	24	25.8
Bilateral grafts		
Yes	8	10.8
Repeat grafts		
Yes	8	10.8

DMEK = Descemet membrane endothelial keratoplasty; DSAEK = Descemet stripping automated endothelial keratoplasty; PBK = pseudophakic bullous keratopathy; PKP = penetrating keratoplasty.
*Other: posttrauma corneal scarring (n = 4), postinfectious corneal scarring (n = 2), keratoconus (n = 1), lattice corneal dystrophy (n = 1).

pachymetry maps as a tool for the early detection of graft rejection or failure within this clinical setting.

AS-OCT for Early Detection of Graft Rejection or Failure

To demonstrate the utility of AS-OCT in the early detection of graft rejection and failure even in the absence of clinical signs and symptoms, we focus on 3 representative cases: 2 with graft rejection and 1 with graft failure.

Case #1: Early Detection and Successful Management of Graft Rejection in the Early Postoperative Period after Ultrathin DSAEK

A 61-year-old patient with previously diagnosed Fuchs endothelial dystrophy underwent ultrathin DSAEK in his left eye. At the 4-week postoperative visit, AS-OCT pachymetry revealed a CCT of 915 μm (Fig 1A), a significant increase of 148 μm compared to the previous AS-OCT performed at the 1-week postoperative visit (767 μm). Cross-sectional AS-OCT images showed a central graft thickness of 136 μm, an increase of 23 μm from the prior measurement of 113 μm (Fig 1B). Despite these notable changes on AS-OCT, no obvious endothelial keratic precipitates were visible on the cross-sectional images (Fig 1B). The patient's visual acuity remained stable at 20/400 compared with his prior visit, and he did not report any symptoms of blurred vision, pain, or light sensitivity. He reported compliance with his prescribed regimen of topical corticosteroid drops (preservative-free dexamethasone 1 mg/ml drops, Dexafree; Thea Laboratories) 4 times daily in the operated eye.

Given the concerning AS-OCT findings, the patient was promptly referred to the cornea attending clinic for a comprehensive evaluation. Slit lamp examination revealed a quiet eye without clinically evident keratic precipitates or anterior chamber inflammation, although the view of the anterior chamber was partially obscured by the edematous cornea. Based on the AS-OCT results and considering the potential for noncompliance and inadequate absorption of the corticosteroid drops, an intensified treatment regimen was initiated. This included hourly administration of preservative-free dexamethasone 1 mg/ml drops (Dexafree; Thea Laboratories) administered hourly during waking hours and a peribulbar injection of triamcinolone 40 mg/ml to rapidly control the presumed inflammatory process.

Ten days later, the patient presented with visible keratic precipitates on slit lamp examination, confirming the diagnosis of graft rejection. Repeat AS-OCT pachymetry showed a decrease in CCT to 736 μm (Fig 2A) compared to the previous value of 915 μm. Cross-sectional images revealed the presence of keratic precipitates adherent to the endothelium and a further decrease in central graft thickness to 85 μm (Fig 2B). The patient was instructed to continue the topical corticosteroid drops on a slow taper and was started on oral prednisone 1 mg/kg daily, with a plan to taper the dose over the subsequent 3 months.

At the 3-month postoperative visit, AS-OCT pachymetry confirmed the successful reversal of the rejection episode, with a marked reduction in CCT to 533 μm (Fig 3A). Central graft thickness had further decreased to 47 μm, and cross-sectional images showed complete clearance of keratic precipitates (Fig 3B). The patient's visual acuity had also improved to 20/40.

This case highlights the critical role of AS-OCT in the early detection and monitoring of graft rejection after ultrathin DSAEK. The significant increase in CCT and graft thickness detected on AS-OCT at the 4-week visit, in the absence of changes in vision, keratic precipitates, or other clinical signs and symptoms, prompted timely intervention with aggressive corticosteroid therapy. It is important to note that detecting a 23 μm increase in graft thickness during the early postoperative period, when the graft is still edematous, is extremely challenging and unreliable using slit lamp examination alone. Serial AS-OCT imaging allowed for objective assessment of the response to treatment and guided further therapeutic decision-making. The successful outcome in this case underscores the value of integrating AS-OCT into the postoperative monitoring protocol for early diagnosis and effective management of graft rejection, ultimately leading to improved visual outcomes for patients undergoing ultrathin DSAEK.

Case #2: Primary Graft Failure after Ultrathin DSAEK

A 77-year-old man with a history of primary open-angle glaucoma and a recently repositioned Ahmed valve implant to the sulcus underwent ultrathin DSAEK in his left eye to treat pseudophakic corneal edema. On the first postoperative day, AS-OCT pachymetry map showed a CCT of 885 μm and a graft thickness of 170 μm (Fig 4A). High-resolution AS-OCT images confirmed a well-attached endothelial graft (Fig 4B). At his first postoperative month visit, the AS-OCT pachymetry map indicated a CCT of

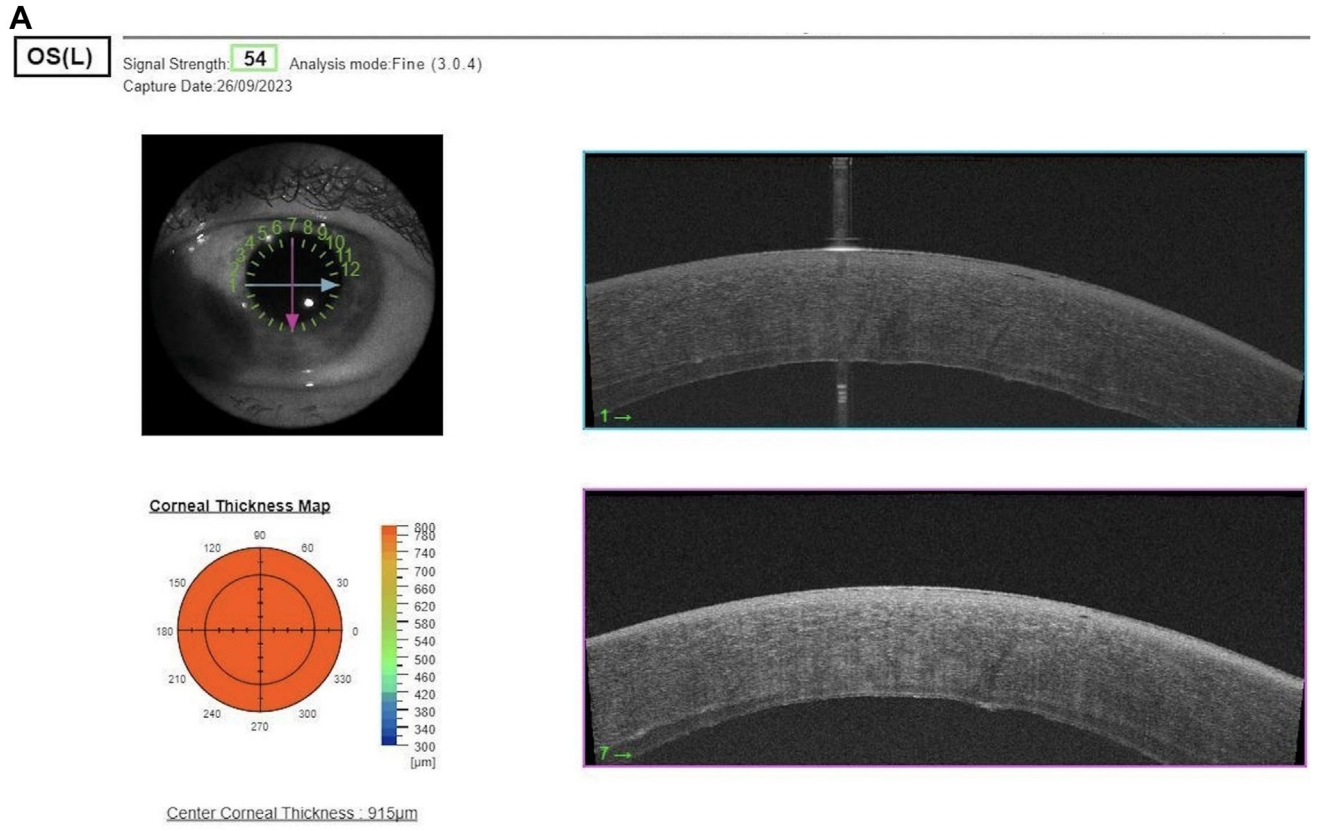

Figure 1. Early signs of graft rejection detected by AS-OCT at 4 weeks post-DSAEK in a patient with Fuchs endothelial dystrophy. **A,** Anterior segment OCT pachymetry map demonstrating a significant increase in CCT to 915 µm, compared to 767 µm at the 1-week postoperative visit. **B,** High-resolution cross-sectional AS-OCT image revealing an increase in central graft thickness to 136 µm, a 23 µm increase from the prior measurement of 113 µm at 1 week postoperatively. No obvious endothelial keratic precipitates were visible at this stage. Based on these AS-OCT findings, the patient was identified as being at high risk for graft rejection and was promptly initiated on intensive topical corticosteroid therapy and administered a peribulbar triamcinolone injection. AS-OCT = anterior segment OCT; CCT = central corneal thickness; DSAEK = Descemet stripping automated endothelial keratoplasty.

852 µm without change in the graft thickness (170 µm) (Fig 5A). Cross-sectional AS-OCT images did not reveal any endothelial keratic precipitates (Fig 5B).

Concerned about potential graft rejection, the patient underwent a thorough evaluation at the cornea attending clinic. Slit lamp examination showed no keratic precipitates, and the limited view of the anterior chamber due to the corneal edema did not suggest active inflammation. The patient was asked to use hourly topical preservative-free dexamethasone drops (Dexafree; Thea Laboratories), and

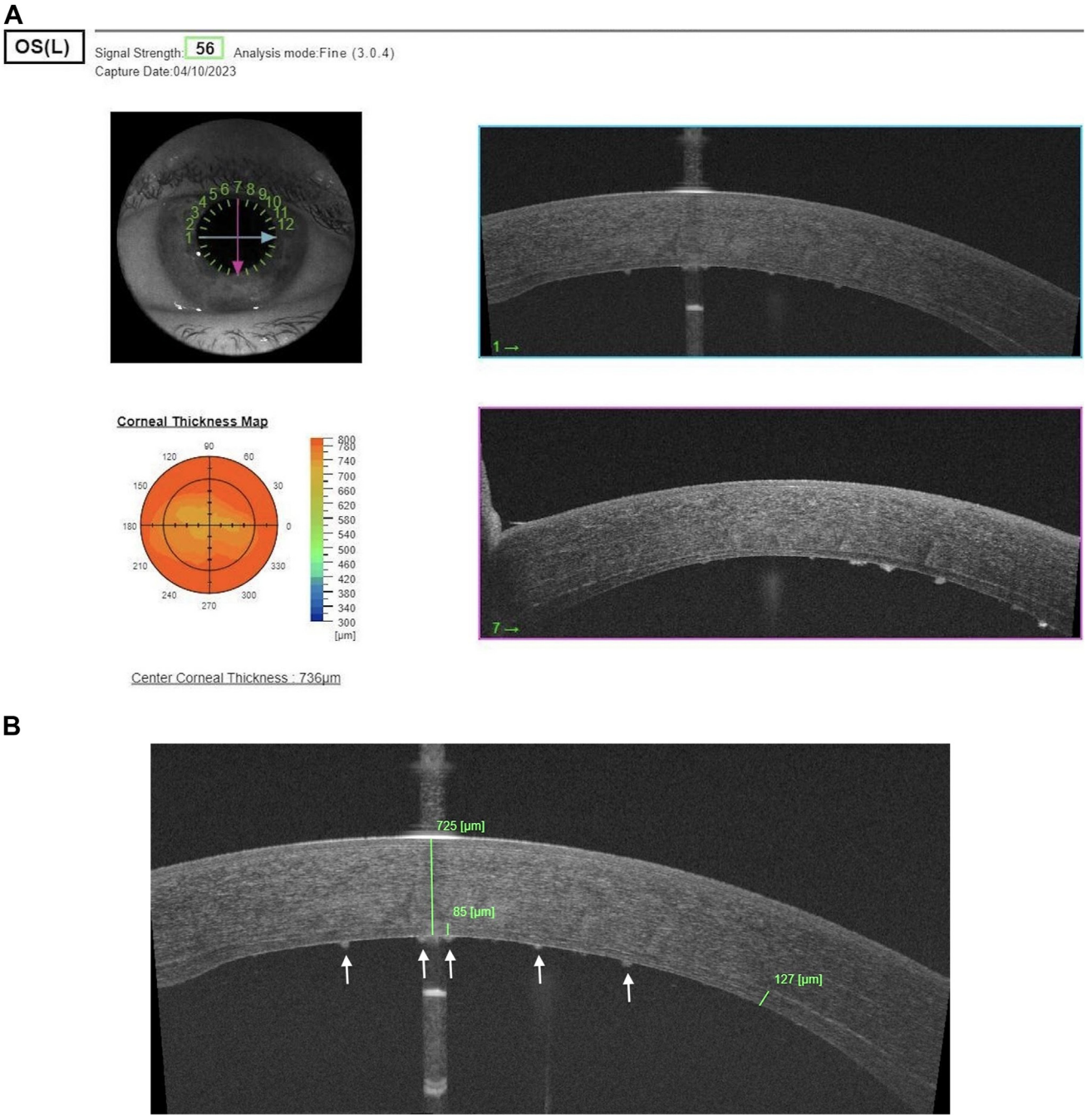

Figure 2. Graft rejection evident on AS-OCT at 6 weeks post-DSAEK. **A,** Anterior segment OCT pachymetry map showing a decrease in CCT to 736 µm, a reduction of 179 µm compared to the previous value of 915 µm at 4 weeks postoperatively. This decrease in CCT is likely due to the early intervention with topical and peribulbar corticosteroids. **B,** High-resolution cross-sectional AS-OCT image clearly depicting the presence of keratic precipitates (arrows) adherent to the endothelial surface of the graft, confirming the ongoing graft rejection process. The central graft thickness has decreased to 85 µm, a reduction of 51 µm from the prior measurement of 136 µm. The patient was instructed to continue the topical corticosteroid drops on a slow taper and was started on oral prednisone 1 mg/kg daily, with a plan to taper the dose over the subsequent 3 months. AS-OCT = anterior segment OCT; CCT = central corneal thickness; DSAEK = Descemet stripping automated endothelial keratoplasty.

he also received a peribulbar injection of triamcinolone 40 mg/ml. An oral methylprednisolone taper was also initiated.

Despite these measures, a follow-up AS-OCT 2 months later revealed only a slight reduction in CCT to 815 µm and a mild reduction in graft thickness to 153 µm (Fig 6A). High-resolution cross-sectional imaging confirmed the absence of keratic precipitates (Fig 6B). Given the minimal reduction in CCT and the clinical nonfunctionality of the graft, the diagnosis was confirmed as primary graft failure.

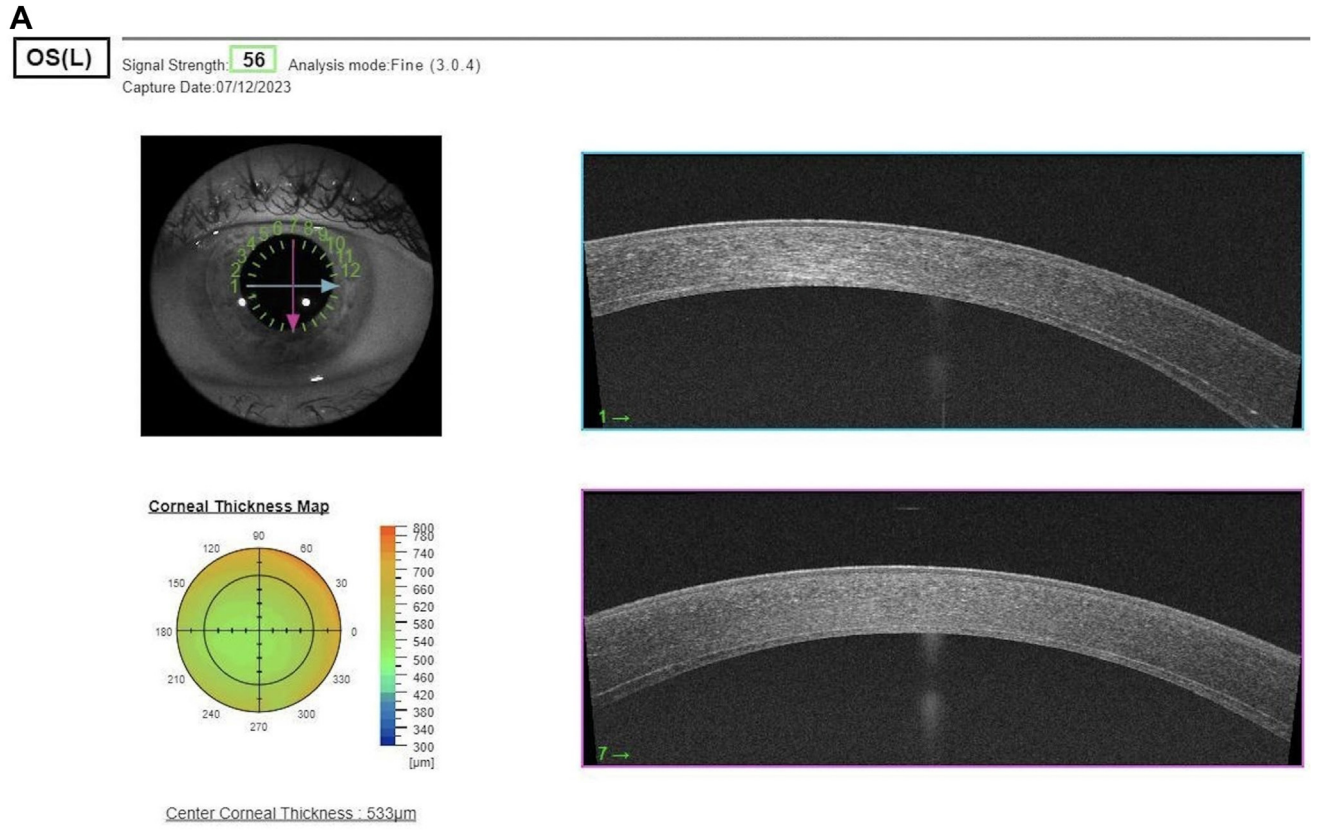

Figure 3. Resolution of graft rejection after aggressive corticosteroid therapy, as demonstrated by AS-OCT at 3 months post-DSAEK. **A,** Anterior segment OCT pachymetry map revealing a significant reduction in CCT to 533 µm, a decrease of 203 µm compared to the value of 736 µm at 6 weeks post-operatively. This marked improvement in corneal thickness indicates the successful reversal of graft edema and the restoration of endothelial function. **B,** High-resolution cross-sectional AS-OCT image confirming the complete clearance of keratic precipitates from the endothelial surface of the graft, signifying the resolution of the inflammatory process. The central graft thickness has further decreased to 47 µm, a reduction of 38 µm from the previous measurement of 85 µm at 6 weeks postoperatively. This thinning of the graft suggests a recovery of endothelial cell function and the restoration of graft deturgescence. AS-OCT = anterior segment OCT; CCT = central corneal thickness; DSAEK = Descemet stripping automated endothelial keratoplasty.

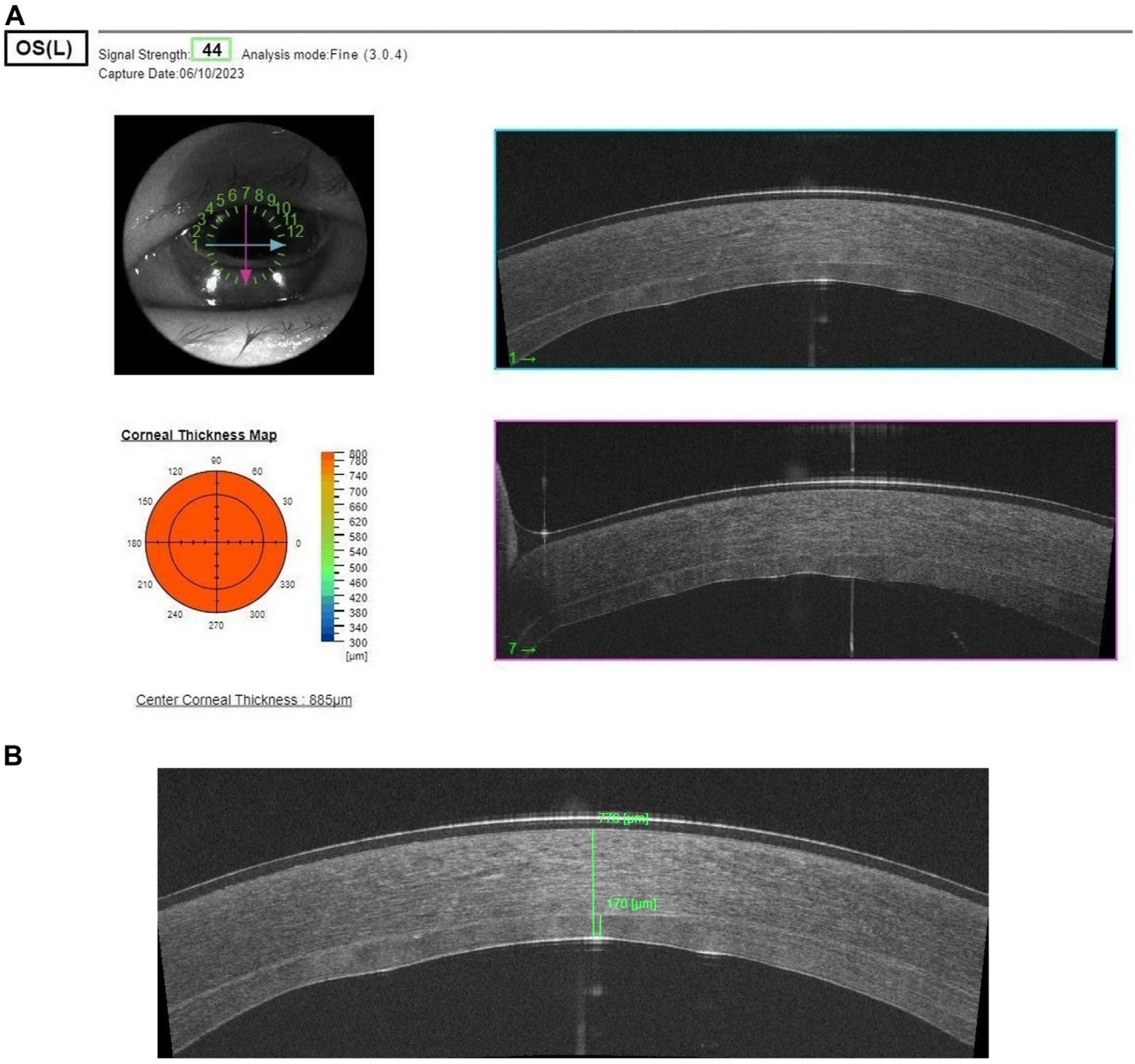

Figure 4. Initial postoperative day 1 AS-OCT findings after ultrathin DSAEK for pseudophakic corneal edema. **A,** Anterior segment OCT pachymetry map displays initial CCT of 885 µm and graft thickness of 170 µm, indicating successful graft attachment. **B,** High-resolution cross-sectional image confirms the complete attachment of the endothelial graft. AS-OCT = anterior segment OCT; CCT = central corneal thickness; DSAEK = Descemet stripping automated endothelial keratoplasty.

The absence of keratic precipitates and minimal changes in graft thickness further supported the diagnosis.

Case #3: Early Detection and Successful Management of Rejection in a Long-Term Monitored Full-Thickness Corneal Graft

A 22-year-old patient with a history of central corneal scarring from prior trauma underwent PKP in his left eye. At the 9-month postoperative visit, AS-OCT pachymetry revealed a CCT of 475 µm without keratic precipitates on cross-sectional images (Fig 7). His visual acuity was recorded at 20/40, and he reported no subjective complaints.

During a routine follow-up 6 months later, although his visual acuity remained stable and he reported no discomfort, repeat AS-OCT pachymetry mapping showed an increase in CCT to 551 µm, an increase of 76 µm (Fig 8A). High-resolution cross-sectional AS-OCT images confirmed this measurement and showed no signs of endothelial keratic precipitates (Fig 8B).

These AS-OCT findings raised concerns for late graft rejection, leading to an immediate referral for a

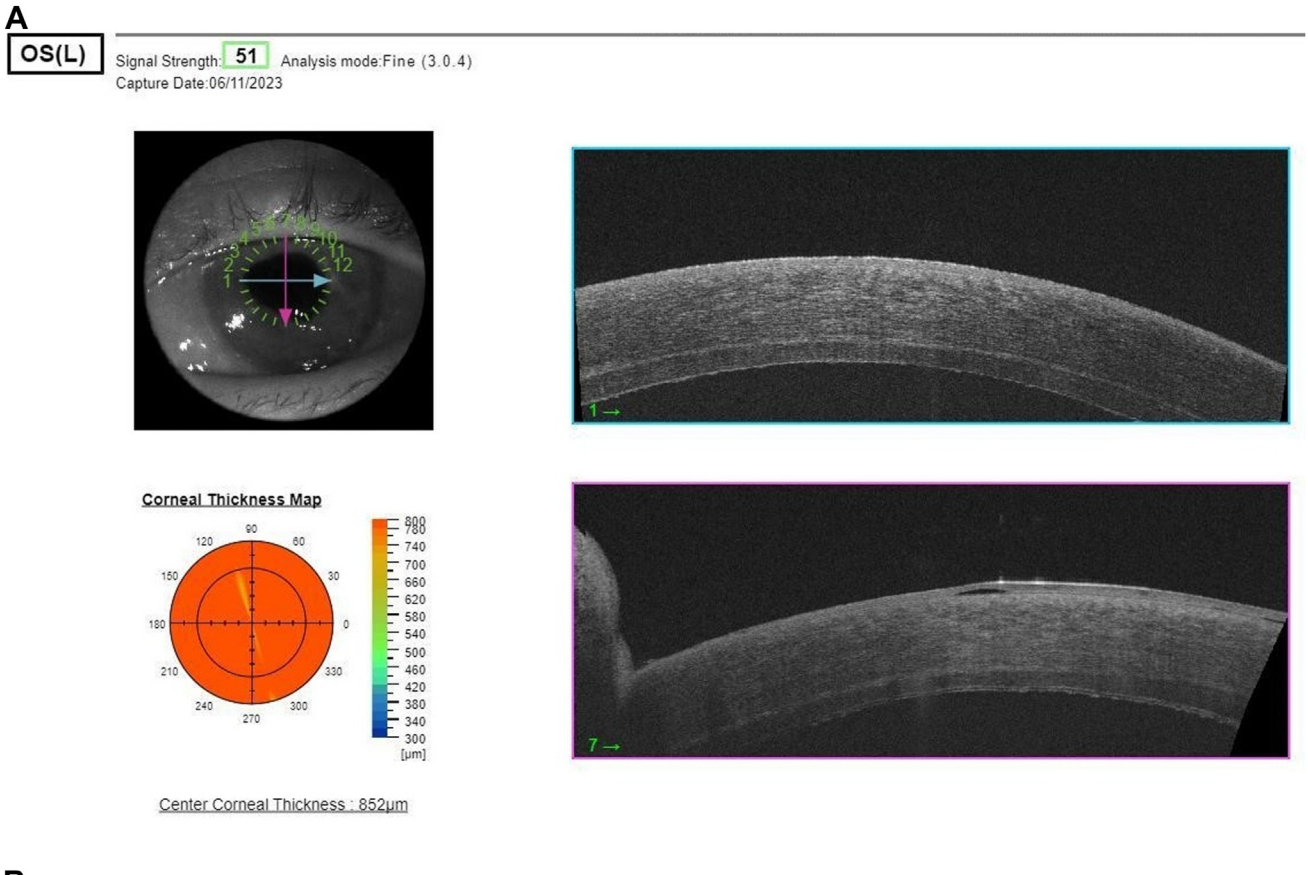

Figure 5. Graft failure or rejection at 1 month post-DSAEK. **A,** Anterior segment OCT pachymetry map showing a CCT of 852 µm without change in the graft thickness (170 µm). **B,** High-resolution AS-OCT image reveals no signs of endothelial keratic precipitates. The patient's treatment plan was intensified with hourly topical corticosteroids, a peribulbar triamcinolone injection, and oral steroids. AS-OCT = anterior segment OCT; CCT = central corneal thickness; DSAEK = Descemet stripping automated endothelial keratoplasty.

comprehensive evaluation at the cornea attending clinic. Slit lamp examination revealed a quiet eye without clinically evident keratic precipitates. Given these findings and the study protocol, the patient was identified as at risk for graft rejection and was initiated on intensive topical therapy with preservative-free dexamethasone 1 mg/ml drops (Dexafree; Thea Laboratories) administered hourly.

The patient was placed on a more intensive follow-up schedule and was reexamined 1 month later. He reported blurry vision, and a decrease in visual acuity to 20/100 was noted. Slit lamp examination now revealed a hazy graft without clinically evident keratic precipitates. Anterior segment OCT pachymetry demonstrated a further increase in CCT to 787 µm (Fig 9A), a significant increase of 236 µm from the month prior (Fig 8A). Cross-sectional AS-OCT images confirmed the thickened graft but still showed no keratic precipitates (Fig 9B).

A differential diagnosis of graft failure versus rejection was considered. Thus, the patient continued hourly topical corticosteroids and received a peribulbar triamcinolone

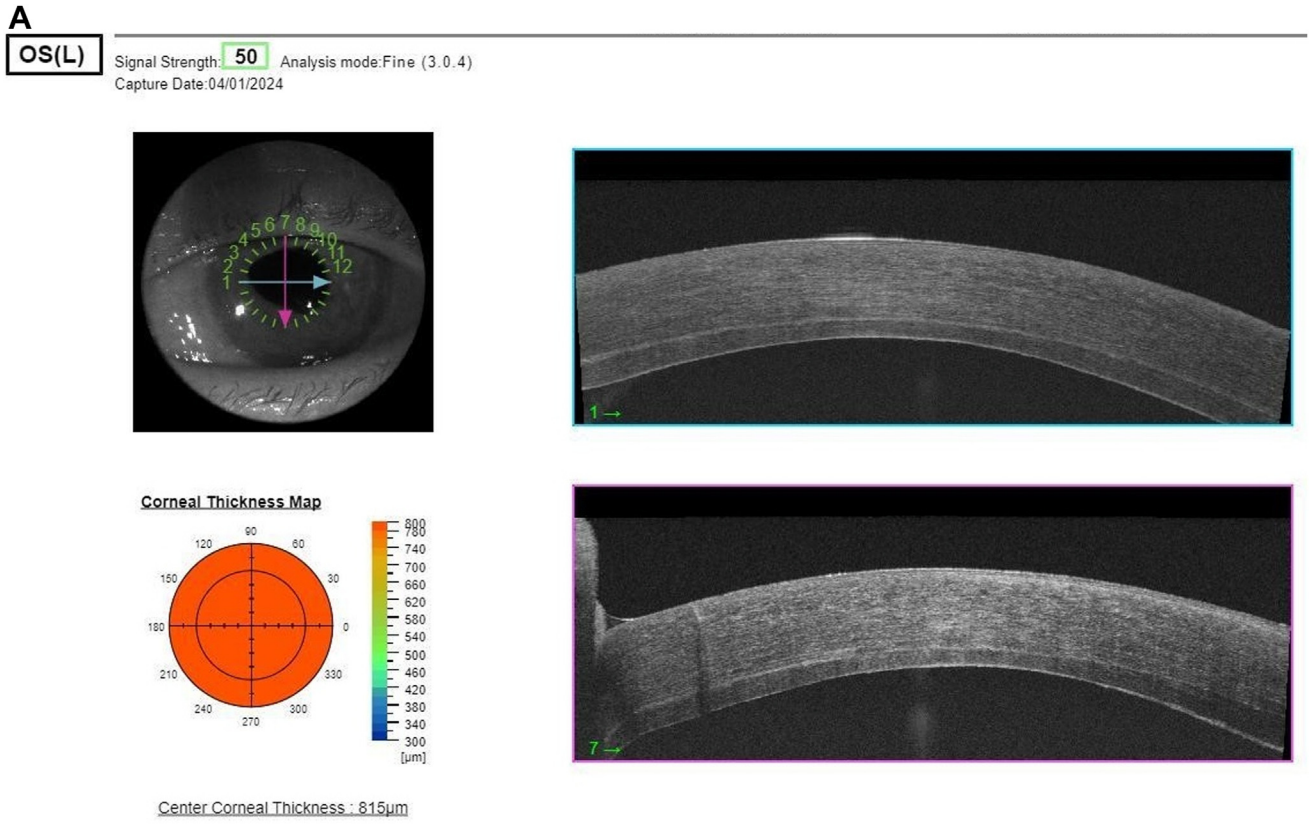

Figure 6. Confirmation of graft failure at 3 months postoperatively. **A,** Anterior segment OCT pachymetry map demonstrates a marginal decrease in CCT to 815 µm and graft thickness to 153 µm. **B,** Cross-sectional AS-OCT imaging shows no keratic precipitates, confirming the absence of rejection but indicating a nonfunctioning graft; AS-OCT = anterior segment OCT; CCT = central corneal thickness.

40 mg/ml injection along with oral prednisone (1 mg/kg daily). One month after initiating aggressive corticosteroid therapy, AS-OCT pachymetry indicated a reduction in CCT to 686 µm (Fig 10A), a reduction of 101 µm from the previous visit (Fig 9A). Keratic precipitates were now visible both clinically and on high-resolution AS-OCT cross-sectional images (Fig 10B).

Three months later, at the patient's 20-month postoperative visit, slit lamp and AS-OCT examinations confirmed the reversal of graft rejection. Central corneal thickness had decreased to 534 µm (Fig 11A), with no keratic precipitates visible on cross-sectional AS-OCT images (Fig 11B). The patient's visual acuity improved to 20/50.

This case underscores the importance of AS-OCT in the early recognition of graft rejection not only in DSAEK but also in PKP cases. Anterior segment OCT's ability to detect subtle increases in CCT—imperceptible on slit lamp examinations and without affecting vision or symptomatology—facilitated a more aggressive follow-up

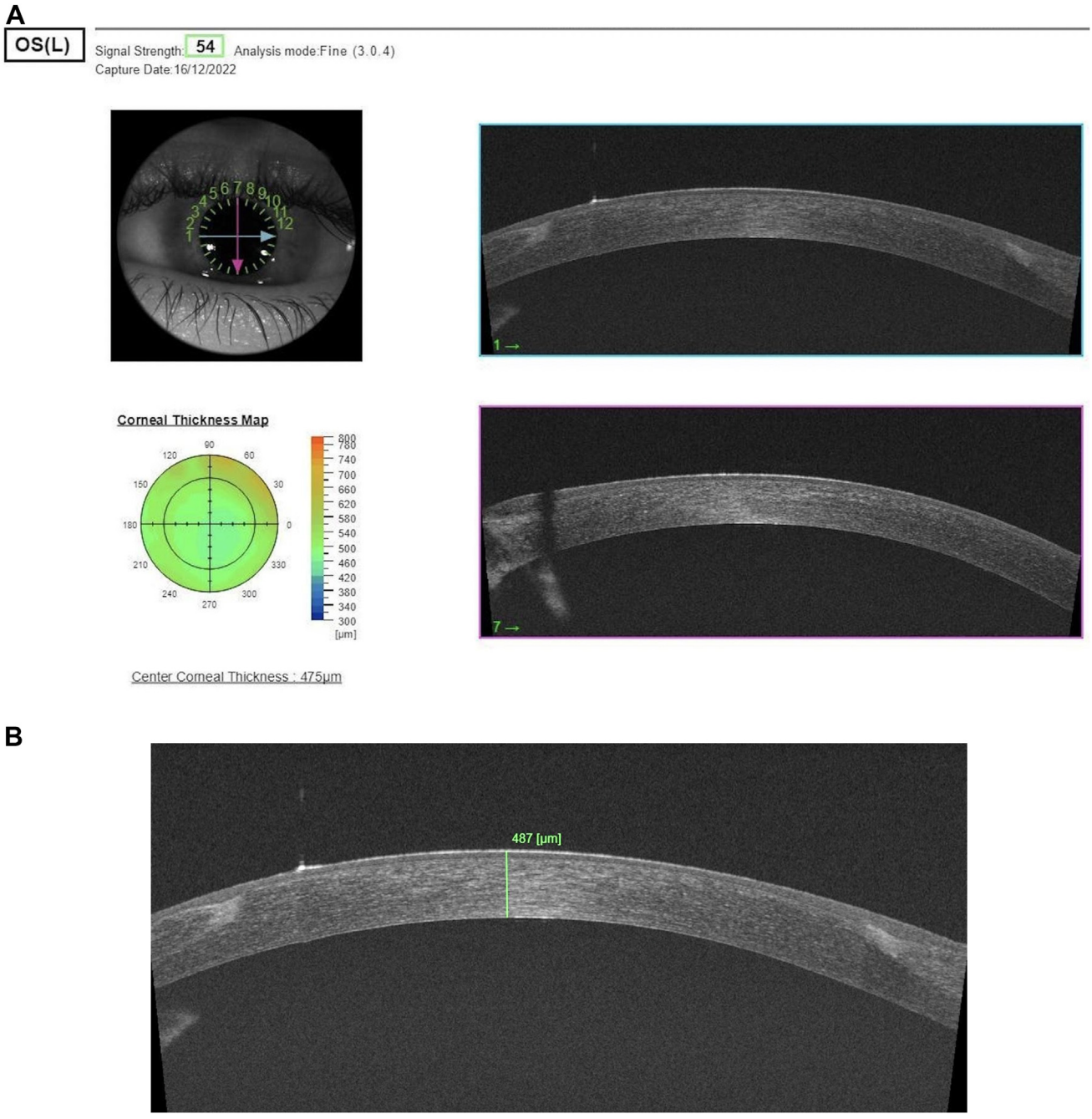

Figure 7. Normal postoperative appearance on AS-OCT of a full thickness corneal graft in a young patient 9 months post-PKP. **A,** AS-OCT pachymetry map showing a central graft thickness of 475 µm. **B,** High-resolution cross-sectional AS-OCT image displaying a normal endothelial bed without keratic precipitates. AS-OCT = anterior segment OCT; PKP = penetrating keratoplasty.

strategy crucial for the graft's survival. Initially presenting without subjective complaints or significant clinical findings, timely interventions guided by AS-OCT findings led to the successful management of graft rejection.

Discussion

This study highlights the pivotal role of AS-OCT in the long-term monitoring of corneal grafts. Our objectives were twofold: firstly, to validate the effectiveness of AS-OCT for the detailed evaluation of corneal grafts, particularly in detecting subclinical signs of dysfunction, and secondly, to assess the integration of AS-OCT within a hybrid remote monitoring protocol.

Our findings confirm that serial AS-OCT imaging provides an objective and quantitative assessment of corneal and graft thickness, facilitating early detection of graft rejection or failure with a sensitivity of 88.9% and specificity of 97.6%. Importantly, AS-OCT detected significant

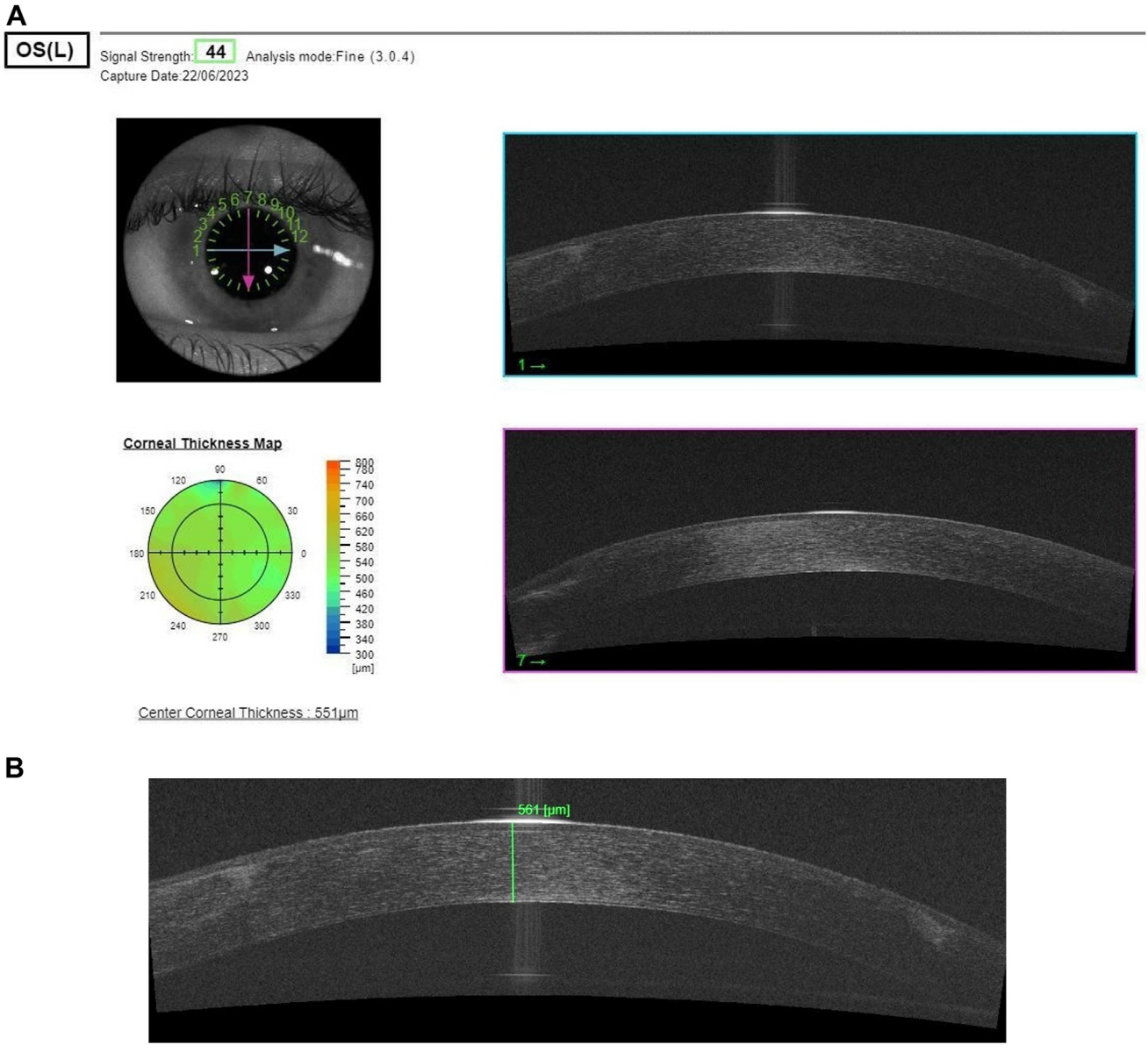

Figure 8. Early signs of potential late graft failure or rejection 15 months post-PKP detected on AS-OCT. **A,** Anterior segment OCT pachymetry map reveals an increased central graft thickness of 551 µm, up by 76 µm from 6 months earlier, suggesting potential graft failure or rejection. **B,** High-resolution AS-OCT image confirms the increased graft thickness without visible endothelial keratic precipitates, prompting initiation of hourly topical corticosteroid therapy; AS-OCT = anterior segment OCT; PKP = penetrating keratoplasty.

changes in corneal and graft thickness in the absence of overt clinical signs and symptoms, as demonstrated in detailed case studies. This capability allowed for the early initiation of intensive corticosteroid therapy, which led to the successful reversal of graft rejections and improved visual outcomes. The cases highlighted reveal that subtle changes, undetectable through traditional slit lamp examination, can indicate impending graft dysfunction. This underscores AS-OCT's utility in capturing critical graft performance metrics earlier than conventional methods.

Traditional corneal graft monitoring largely relies on slit lamp biomicroscopy, a technique that, although standard, is limited by its subjectivity and variability in detecting subtle yet critical graft changes. Anterior segment OCT, in contrast, offers quantifiable, reproducible data that reduce interobserver variability and increase diagnostic accuracy. This transition to a more standardized, objective form of postoperative assessment could potentially streamline and enhance postoperative care protocols. It is remarkable to note that during the screening intervals, the average CCT increase in the cases that developed rejection or failure was 82.7 ± 21.5 µm, a thickness change that goes undetectable on slit lamp examination and does not lead to changes in vision. In fact, this increase in CCT demonstrated graft dysfunction before anterior segment inflammation and keratic precipitates were seen on slit lamp examination, as

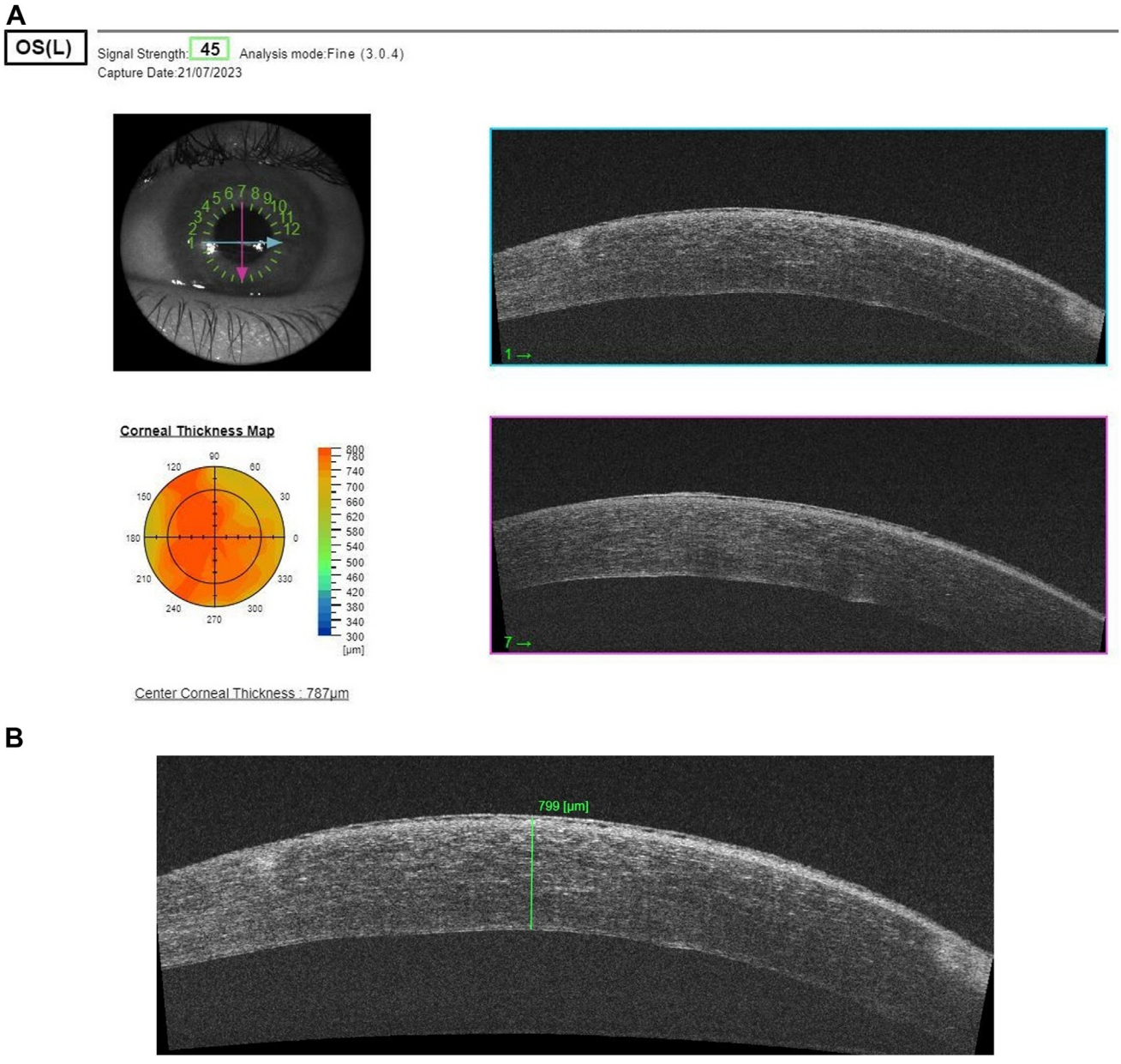

Figure 9. Progression of potential graft failure or rejection indicated by AS-OCT 16 months post-PKP. **A,** Anterior segment OCT pachymetry map shows a central graft thickness of 787 μm, a substantial increase of 236 μm within 1 month, signaling a worsening condition. **B,** High-resolution AS-OCT image depicts a thickened graft without keratic precipitates. The patient was escalated to intensive treatment with hourly topical corticosteroids, a peribulbar triamcinolone injection, and oral steroids. AS-OCT = anterior segment OCT; PKP = penetrating keratoplasty.

described in detail in the cases previously highlighted. Thus, the use of AS-OCT pachymetry maps as part of a screening protocol for graft dysfunction does not compromise the quality of postoperative care. Rather, it enhances patient care by enabling accurate monitoring and timely intervention, ensuring that in-person evaluations are strategically utilized to optimize both resources and patient outcomes.

Although numerous studies have examined the relationship between postoperative corneal and graft thickness after endothelial keratoplasty and postoperative visual acuity, demonstrating that increased thickness correlates with poorer visual outcomes,[7–10] the association of postoperative thickness and the risk of graft failure or rejection has been less frequently explored.[11–14]

Verdier et al[11] noted an association between increased corneal thickness, measured via ultrasound pachymetry, and graft failure of PKP grafts in a subset of 887 participants from the well-designed prospective randomized Cornea Donor Study. Although the authors cautioned against using CCT measurements as the sole indicator of corneal health, they highlighted the potential for future research to improve CCT's utility in assessing prophylaxis or treatment options for graft failure or rejection. In particular, they proposed exploring whether CCT and endothelial

Figure 10. Reversal of graft rejection after intensive corticosteroid therapy as evidenced by AS-OCT 17 months postoperatively. **A,** Anterior segment OCT pachymetry map shows a reduction in central graft thickness to 686 µm from 787 µm, reflecting the response to treatment. **B,** High-resolution AS-OCT image captures keratic precipitates (arrows) adhering to the endothelium, indicative of ongoing immunological activity despite the reduced thickness post intensive corticosteroid therapy. AS-OCT = anterior segment OCT.

cell density measurements could guide more aggressive or prolonged steroid treatments in cases of mild rejection or inflammation.[11]

Further, Shih et al used a slit lamp AS-OCT system to predict primary graft failure of DSAEK grafts in the early postoperative period. Their findings indicated that a DSAEK lenticule thickness of ≤350 µm at 1 week after surgery was associated with a success rate exceeding 98%.[12] Finally, Eleiwa et al[13] showed that 3-dimensional AS-OCT thickness maps of the endothelium and Descemet membrane complex exhibit high sensitivity and specificity in detecting active clinically evident graft rejection. These maps, although generated by proprietary software and not widely accessible, have been used prospectively to predict graft rejection in high-risk corneal grafts through a single measurement in the first postoperative year.[14] In contrast, AS-OCT-generated pachymetry maps are readily accessible across various commercially available OCT models, and their use to predict graft dysfunction is not limited to high-risk grafts.

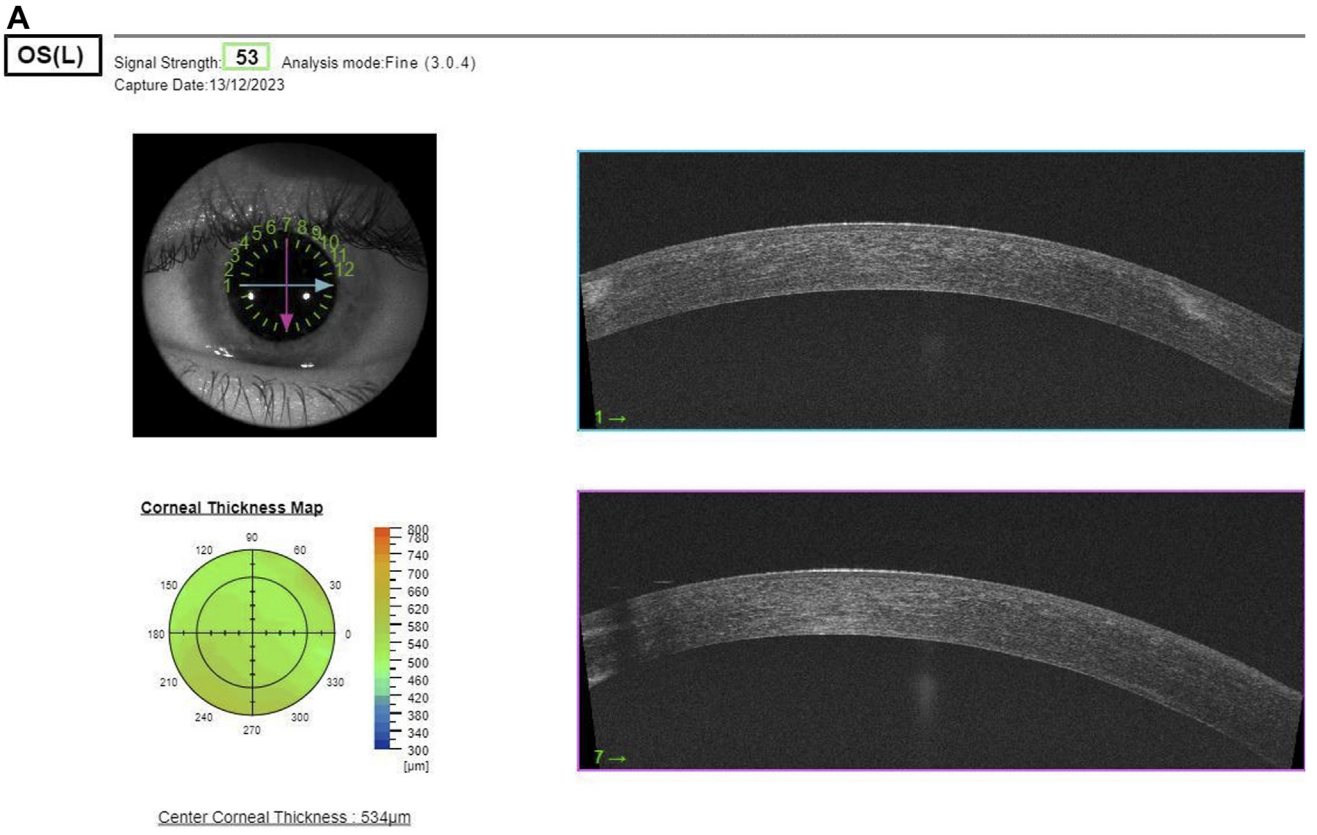

Figure 11. Established reversal of graft rejection 4 months after intensive corticosteroid therapy. **A,** Anterior segment OCT pachymetry map displays a central graft thickness of 534 μm, a significant reduction from 787 μm, suggesting effective control of graft rejection. **B,** High-resolution AS-OCT cross-sectional image confirming the decrease in graft thickness and the absence of keratic precipitates, indicative of restored endothelial function. The patient's visual acuity improved to 20/50, confirming the clinical success of the treatment regimen. AS-OCT = anterior segment OCT.

However, serial measurements are needed in order to detect subtle changes in graft thickness effectively.

Integrating AS-OCT into a screening protocol represents a forward-thinking approach to postoperative care. By minimizing direct follow-ups while maintaining crucial specialist oversight for anomalies detected via AS-OCT, our model enhances care efficiency and patient throughput. This hybrid model addresses both the logistical challenges of frequent patient visits and the need for specialist intervention when necessary, making it particularly beneficial in regions with limited access to specialized care.[15] Although the data capture requires patient presence, the subsequent analysis and monitoring are designed to maximize the efficiency and scope of remote care capabilities.

Our study, although providing valuable insights into AS-OCT's utility in corneal graft monitoring, has several limitations. The efficacy of the hybrid remote monitoring protocol is heavily dependent on patient adherence to scheduled AS-OCT screenings and treatment regimens, and variability in adherence could potentially alter results. Additionally, the technical and cost barriers associated with AS-OCT equipment, along with the necessary training for health care

providers and technicians, may limit its adoption, particularly in resource-limited settings. Additionally, we did not compare AS-OCT with other commonly available tomographic tools that provide total corneal pachymetric maps, such as Scheimpflug-based tomography, which could provide further insights into AS-OCT's relative effectiveness in detecting subtle changes in corneal thickness.

The ability of AS-OCT to provide accurate, real-time data makes it an excellent tool for corneal graft monitoring, potentially transforming postoperative care by allowing for earlier detection and intervention, thus preventing irreversible graft damage. Failure to identify early endothelial malfunction places the graft at risk, and this greatly affects the productivity and quality of life of the patient. On top of that, it can generally increase the costs of care, leading to a substantial strain on the health care system. Hence, the need for a diagnostic approach that will be easily performed and provide objective markers and reproducible findings is imperative. Although AS-OCT is a sophisticated tool requiring specific training, its capacity to provide detailed, reproducible data justifies its integration into routine follow-up for corneal graft patients, especially in settings equipped to handle such technology. Our study has shown that it is a sensitive tool that provides objective indices regarding the graft's performance. Nonetheless, further studies with larger sample sizes that explore the long-term outcomes of AS-OCT monitored corneal grafts are required.

The utility of AS-OCT in the long-term monitoring of corneal grafts extends beyond mere anatomical assessment; it serves as a critical tool in the early detection of potential graft failure and rejection, thereby enabling timely and targeted interventions. The integration of AS-OCT into routine postoperative care and remote screening protocols could significantly enhance patient outcomes, optimize resource utilization, and lead to more proactive and personalized care strategies.

Data Availability Statement

All datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Footnotes and Disclosures

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Abbreviations and Acronyms:
AS-OCT = anterior segment OCT; **CCT** = central corneal thickness; **DMEK** = Descemet membrane endothelial keratoplasty; **DSAEK** = Descemet stripping automated endothelial keratoplasty; **PKP** = penetrating keratoplasty.

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