

Identification of a Horizontal Invasion Length Threshold Predicting Posterior Corneal Flattening after Pterygium Excision

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Purpose: To characterize perioperative changes in posterior corneal curvature (PCC) following pterygium excision using anterior segment (AS) swept-source optical coherence tomography (SS-OCT), and to identify the critical threshold of horizontal invasion length (HIL) predicting significant PCC alterations.

Methods: This retrospective cohort study included 85 eyes of 77 patients with primary nasal pterygium. PCC parameters, including posterior keratometry (K) average, posterior steep K, posterior flat K and posterior corneal astigmatism, were measured preoperatively and postoperatively using AS SS-OCT (Anterior). Perioperative PCC changes were analyzed in relation to HIL and postoperative duration. Subgroup analyses were performed to identify the HIL cutoff value associated with statistically significant changes in posterior K average.

Results: Significant postoperative flattening was observed in both posterior K average (from -6.27 ± 0.24 to -6.23 ± 0.23 diopters [D], $p < 0.001$) and posterior flat K (from -6.14 ± 0.23 to -6.09 ± 0.23 D, $p < 0.001$), accompanied by a significant increase in posterior corneal astigmatism (from -0.25 ± 0.12 to -0.29 ± 0.17 D, $p = 0.003$). The magnitude of posterior flattening showed a significant positive correlation with HIL ($r = 0.384$, $p < 0.001$) but was not correlated with postoperative duration ($p = 0.428$). In subgroup analysis, eyes with HIL ≥ 3.5 mm exhibited a significant change in posterior K average ($p < 0.001$), whereas those with HIL < 3.0 mm and HIL < 3.5 mm showed no significant change ($p = 0.065$ and $p = 0.443$, respectively).

Conclusions: Pterygium excision leads to significant posterior corneal flattening proportional to HIL, with 3.5 mm identified as a clinically relevant cutoff. Although the refractive impact may be subtle, surgeons should be aware of these posterior corneal changes as a consistent morphological response, especially in eyes with HIL ≥ 3.5 mm.

Key Words: Anterior, Horizontal invasion length, Optical coherence tomography, Posterior corneal curvature, Pterygium

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Pterygium is a triangular fibrovascular proliferative lesion originating from the conjunctiva, crossing the limbus, and extending onto the cornea, predominantly arising from the nasal side [1]. Previous studies utilizing the autokeratometry and placido-based corneal topography consistently reported that the tractional force exerted by the pterygium flattened the horizontal meridian of the anterior cornea

[2], and that the resolution of this distortion following pterygium excision resulted in the steepening of the mean refractive power of the cornea [3]. Furthermore, these investigations established a significant correlation between the extent of pterygium corneal invasion and the magnitude of change in the corneal mean refractive power observed perioperatively [4].

As pterygium directly influences the corneal refractive power, it can critically affect the determination of the intraocular lens (IOL) power, which is paramount in cataract surgery [5]. Consequently, research has focused on predicting the change in corneal refractive power after pterygium excision, specifically by leveraging the established correlation between the pterygium's corneal invasion length and the change in corneal refractive power [6]. Furthermore, studies have been conducted to determine the optimal timing for cataract surgery after pterygium excision by identifying the period required for these corneal refractive changes to fully stabilize [7].

Previous investigations of corneal refractive changes following pterygium excision predominantly used values calculated based on the anterior corneal surface, such as those derived from autokeratometry and corneal topography. However, pterygium removal can induce significant alterations in corneal shape and surface irregularity, undermining the validity of estimating total corneal power from the anterior curvature alone using the conventional keratometric index of 1.3375 [8]. Consequently, comprehensive evaluation of posterior corneal curvature (PCC) changes is essential to fully characterize postoperative corneal refractive alterations and to improve predictive models of total corneal power in these eyes. Nevertheless, previous studies on PCC using Scheimpflug-based corneal tomography have yielded inconsistent results. Some reported statistically significant changes [9], while others found no statistically significant difference [10].

The inconsistency among previous studies may stem from the limited resolution and measurement variability of Scheimpflug-based tomography, particularly in eyes with irregular corneal surfaces [11]. With the advent of high-resolution anterior segment (AS) swept-source optical coherence tomography (SS-OCT), PCC can now be assessed with greater precision, as AS SS-OCT provides superior axial resolution and better delineation of the posterior corneal boundary, which is often compromised by light scatter in Scheimpflug systems [12,13]. Therefore, this study

aimed to characterize perioperative PCC changes using AS SS-OCT, determine their relationship with the extent of pterygium invasion.

Materials and Methods

Ethics statement

This study was approved by the Institutional Review Board of Chung-Ang University Hospital (No. 2510-020-19598) and was conducted in accordance with the principles of the Declaration of Helsinki. The requirement for informed consent was waived due to the use of deidentified data and the retrospective nature of the study.

Subjects

This study reviewed the medical records of patients who underwent pterygium excision at the Department of Ophthalmology, Chung-Ang University Hospital, between September 2021 and June 2023. A total of 77 subjects (85 eyes) were included in the final analysis. The inclusion criteria were as follows: (1) diagnosis of nasal area-only primary pterygium and subsequent surgical excision; (2) pterygium confined to the nasal side; and (3) successful measurement of PCC using AS SS-OCT at least 4 weeks postoperatively. The exclusion criteria were as follows: (1) a history of prior pterygium surgery; (2) eyes that exhibited recurrence during the postoperative follow-up period; (3) double-headed pterygium; and (4) a history of corneal refractive surgery, such as laser *in situ* keratomileusis (LASIK) or laser epithelial keratomileusis (LASEK).

Main outcome measures

The analyses are outlined as follows: (1) evaluation of perioperative changes in PCC; (2) assessment of the association between horizontal invasion length (HIL) of pterygium and PCC changes; and (3) estimation of the HIL cutoff value for PCC changes (subgroup analysis).

Clinical severity grading of pterygium

The clinical severity of the pterygium was classified using an established clinical grading system, Tan grade (T

grade), which evaluates the degree of pterygium body translucency [14]. In this system, T1 is assigned when the underlying episcleral vessels are fully visible through the pterygium stroma. T2 indicates cases where the vessels are partially obscured, and T3 represents pterygia where the episcleral vessels are entirely hidden by the opaque pterygium body.

Surgical procedures

A single surgeon (KWK) performed all procedures using a standardized procedure. After administration of local anesthesia, the boundaries of the pterygium to be excised were marked with a surgical pen. Lidocaine 2% was injected into the conjunctival tissue to enable hydrodissection, separating the epithelial layer from the underlying fibrovascular tissue. The fibrovascular component was carefully removed using microsurgical scissors, and the portion of the pterygium invading the cornea was gently excised. A conjunctival limbal autograft was then harvested from the conjunctival donor site and shaped to fit the exposed scleral bed. The graft was placed over the scleral bed and fixed using a combination of fibrin glue (Greenplast Q prefilled syringe, GC Biopharma Corp.) and 10-0 nylon sutures.

Postoperatively, patients were prescribed topical moxifloxacin 0.5% eye drops (Vigamox ophthalmic solution, Novartis) four times daily and a dexamethasone-neomycin ophthalmic ointment (Maxitrol ointment, Novartis) twice daily. In addition, 20% autologous serum eye drops were administered six times daily during the first postoperative week, with a gradual taper over the following month to promote epithelial wound healing. Oral prednisolone (10 mg daily for 5 days) was also administered to help modulate postoperative inflammation.

AS SS-OCT-based parameters of PCC and corneal invasion extent of pterygium

PCC parameters were evaluated preoperatively and postoperatively using the AS SS-OCT (Anterion, Heidelberg Engineering) system to measure the HIL and PCC parameters, including posterior keratometry (K) average, posterior steep K, posterior flat K, and posterior corneal astigmatism, all of which were acquired from the central 3.0 mm ring of the cornea. Posterior corneal parameters are expressed in negative diopters (D) to reflect the diverging op-

tical nature of the posterior corneal surface, which acts as a concave lens. Consequently, a change in value toward zero (decrease in absolute magnitude) is referred to as “flattening,” while a shift away from zero (increase in absolute magnitude) is referred to as “steepening.”

The extent of pterygium corneal invasion, referred to as HIL (mm), was measured on AS SS-OCT images. HIL was defined as the linear distance from the vertical line connecting the anterior chamber angle to a point vertically extended on a surface tangent line at the distal end of the pterygium head, according to previously described methodology [15].

Statistical analysis

All statistical analyses were performed using GraphPad Prism (GraphPad). Preoperative and postoperative PCC parameters were compared using paired *t*-tests for normally distributed variables, and Wilcoxon signed rank tests for non-normally distributed variables. The Spearman rank correlation test was used to evaluate the relationship between changes in PCC and continuous clinical variables, including HIL and postoperative duration. For subgroup analysis based on HIL cutoffs, paired *t*-tests were used to assess perioperative changes within each subgroup. Continuous variables are presented as mean $\pm$ standard deviation. A *p*-value of <0.05 was considered statistically significant. As the subgroup analyses aimed to identify an exploratory clinical threshold, adjustments for multiple comparisons were not applied.

Results

Demographic and clinical characteristics of pterygium

Table 1 presents the demographic and clinical characteristics of the study subjects. A total of 77 subjects (85 eyes) with pterygium were included in the study, and the mean age was 57.6 ± 11.3 years. The subjects comprised 40 men (51.9%) and 37 women (48.1%). Analysis of the T grade showed that the T2 grade accounted for the largest proportion, with 60 eyes (70.6%), followed by the T1 grade with 13 eyes (15.3%) and the T3 grade with 12 eyes (14.1%). The mean HIL of the pterygium was measured as 3.97 ± 1.23 mm.

Perioperative changes in PCC parameters measured by AS SS-OCT

Several PCC parameters measured by AS SS-OCT showed significant changes following pterygium excision (Table 2). Both the posterior K average and posterior flat K values became significantly flatter postoperatively, decreasing from -6.27 ± 0.24 to -6.23 ± 0.23 D and from -6.14 ± 0.23 to -6.09 ± 0.23 D, respectively ($p < 0.001$). Furthermore, the magnitude of posterior corneal astigmatism significantly increased, changing from -0.25 ± 0.12 D preoperatively to -0.29 ± 0.17 D postoperatively ($p = 0.003$). In contrast, the change in the posterior steep K value, from -6.39 ± 0.26 to -6.38 ± 0.27 D, was not statistically significant ($p = 0.144$).

Table 1. Demographic and clinical characteristics of subjects with pterygium

Characteristic	Value
No. of subjects	77
No. of eyes	85
Age (yr)	57.6 ± 11.3
Sex	
Male	40 (51.9)
Female	37 (48.1)
T grade	
T1	13 (15.3)
T2	60 (70.6)
T3	12 (14.1)
HIL (mm)	3.97 ± 1.23

Values are presented as number only, mean $\pm$ standard deviation, or number (%).

HIL = horizontal invasion length.

Correlation of HIL and postoperative duration with perioperative changes in PCC

The correlation analysis between perioperative changes in the PCC parameters critical for IOL power calculation (posterior K average and posterior flat K) and both HIL and postoperative duration is summarized in Table 3. The perioperative change of posterior K average showed a significant positive correlation with HIL ($r = 0.384$, $p < 0.001$). This indicates that a greater extent of pterygium corneal invasion (longer HIL) is associated with a larger magnitude of postoperative flattening of the posterior K average. Conversely, the perioperative change of posterior flat K did not show a statistically significant correlation with HIL ($r = 0.195$, $p = 0.073$). Furthermore, the postoperative duration showed no statistically significant correlation with either the perioperative change of posterior K average ($r = -0.087$, $p = 0.428$) or the perioperative change of posterior flat K ($r = -0.082$, $p = 0.455$).

Determination of the HIL cutoff value for significant perioperative changes in posterior K average

Table 4 presents the subgroup analysis of perioperative changes in the posterior K average stratified by various HIL cutoffs. When the cutoff was set at 3.0 mm and 3.5 mm, the groups with HIL <cutoff showed no significant difference in posterior K average between preoperative and postoperative values ($p = 0.065$ and $p = 0.443$, respectively). Specifically, the HIL <3.5 mm group ($n = 30$) changed from -6.27 ± 0.25 to -6.26 ± 0.25 D without significance ($p = 0.443$). In contrast, the HIL ≥ 3.5 mm group ($n = 55$) showed a significant reduction from -6.26 ± 0.24 to -6.21 ± 0.22 D ($p < 0.001$). Similarly, for the 3.0 mm cutoff, the HIL <3.0 mm group ($n = 23$; -6.27 ± 0.27 to -6.26 ± 0.26 D,

Table 2. Changes in posterior corneal curvature parameters after pterygium excision measured by anterior segment swept-source optical coherence tomography

Variable	Preoperative value	Postoperative value	<i>p</i> -value
Posterior K average (D)*	-6.27 ± 0.24	-6.23 ± 0.23	$<0.001^{\dagger}$
Posterior steep K (D)*	-6.39 ± 0.26	-6.38 ± 0.27	0.144
Posterior flat K (D)*	-6.14 ± 0.23	-6.09 ± 0.23	$<0.001^{\dagger}$
Posterior corneal astigmatism (D) [‡]	-0.25 ± 0.12	-0.29 ± 0.17	$0.003^{\dagger}$

Values are presented as mean $\pm$ standard deviation.

K = keratometry; D = diopters.

*Paired *t*-test; [†] $p < 0.05$; [‡]Wilcoxon signed rank test.

Table 3. Correlation of HIL and postoperative duration with perioperative changes in posterior corneal curvature after pterygium excision

Perioperative change parameter	HIL (mm)		Postoperative duration (wk)	
	r	p-value*	r	p-value*
Posterior K average (D)	0.384	<0.001 [†]	-0.087	0.428
Posterior flat K (D)	0.195	0.073	-0.082	0.455

HIL = horizontal invasion length; K = keratometry; D = diopters.

*Spearman rank correlation test; [†]Statistically significant ($p < 0.05$).

Table 4. Subgroup analysis of perioperative changes in posterior K average after pterygium excision according to HIL

HIL cutoff (mm)	Group	No. of eyes	Posterior K average (D)		p-value*
			Preoperative	Postoperative	
3.0	<3.0	23	-6.27 ± 0.27	-6.26 ± 0.26	0.065
	≥3.0	62	-6.26 ± 0.23	-6.21 ± 0.23	<0.001 [†]
3.5	<3.5	30	-6.27 ± 0.25	-6.26 ± 0.25	0.443
	≥3.5	55	-6.26 ± 0.24	-6.21 ± 0.22	<0.001 [†]
4.0	<4.0	48	-6.26 ± 0.24	-6.24 ± 0.24	0.001 [†]
	≥4.0	37	-6.27 ± 0.25	-6.20 ± 0.23	<0.001 [†]
4.5	<4.5	53	-6.26 ± 0.24	-6.24 ± 0.24	0.001 [†]
	≥4.5	32	-6.27 ± 0.24	-6.20 ± 0.23	<0.001 [†]
5.0	<5.0	65	-6.27 ± 0.25	-6.24 ± 0.25	<0.001 [†]
	≥5.0	20	-6.24 ± 0.21	-6.19 ± 0.20	0.004 [†]

Values are presented as number only or mean ± standard deviation.

K = keratometry; HIL = horizontal invasion length; D = diopters.

*Paired *t*-test; [†]Statistically significant ($p < 0.05$).

$p = 0.065$) showed no significant change, whereas the HIL ≥3.0 mm group ($n = 62$; -6.26 ± 0.23 to -6.21 ± 0.23 D, $p < 0.001$) exhibited a significant change. For all subsequent cutoffs at 4.0, 4.5, and 5.0 mm, the posterior K average significantly decreased in all subgroups. In summary, a preoperative HIL of ≥3.5 mm was identified as a potential cutoff associated with significant postoperative changes in PCC, specifically showing a tendency toward flattening.

Discussion

In this study, we sought to investigate whether pterygium excision affects PCC perioperatively. Our findings indicate that the posterior cornea flattens postoperatively, as reflected by significant decreases in both posterior K average and posterior flat K. Among these changes, the alteration in posterior K average was found to correlate significantly with the HIL, with no significant change observed

when HIL was less than 3.5 mm. Furthermore, the changes in PCC were not influenced by the postoperative time duration, indicating that the posterior cornea does not exhibit gradual stabilization over time. This focus on the PCC values change is clinically significant because the posterior K average directly influences the total corneal refractive power, a key parameter in IOL power calculation [16]. These results reaffirm and extend previous recommendations that pterygium excision should be considered prior to cataract surgery, emphasizing the impact on PCC. Moreover, performing cataract surgery concurrently with pterygium excision may result in refractive inaccuracies due to postoperative alterations in PCC, especially in cases where HIL exceeds 3.5 mm.

Levinger et al. [9] reported that the posterior flat K and posterior mean K become steeper after pterygium excision. The difference in the direction of change is likely due to the superior axial resolution of the AS SS-OCT compared to the Galilei dual Scheimpflug analyzer (Galilei, Ziemer)

utilized in previous studies, which has been shown to provide significantly higher repeatability and reliability in measuring PCC, particularly in eyes with irregular corneal surfaces [12,13]. The AS SS-OCT's ability to precisely delineate the posterior corneal surface minimizes errors from light scatter and corneal surface irregularities common in pterygium-affected eyes, suggesting that the observed posterior corneal flattening pattern reflects a more reliable measurement of the morphologic change following the release of pterygium traction. Levinger et al. [9] noted that the reduction in posterior corneal astigmatism resulted from a relatively greater steepening of the posterior flat K than posterior steep K. Our study also demonstrated that the notable increase in posterior corneal astigmatism was due to a relatively greater flattening of the posterior flat K compared with the minimal change in posterior steep K. This indicates that pterygium excision consistently induces a mechanically asymmetrical response in the posterior cornea, predominantly affecting the flatter meridian. This phenomenon is hypothesized to occur because the nasal pterygium's tractional force is primarily exerted along the horizontal meridian, causing the inherently flatter meridian to undergo a more significant stress-release-induced shape change postexcision. Unlike the study by Levinger et al. [9], which did not analyze the quantitative relationship between PCC change and horizontal pterygium size, our study demonstrated that the posterior K average change correlates with the HIL, highlighting HIL as a robust morphological predictor for the magnitude of PCC alteration regardless of the measurement technique or the specific direction of the curvature change.

The extent of overgrowth onto the cornea of pterygium has been widely used as a key metric for quantitatively grading its severity [17]. Based on previous observations that pterygium invasion length significantly influences anterior corneal changes [18] and their stabilization [7], we hypothesized that HIL would also influence postoperative posterior corneal changes, and indeed, we identified a statistically significant positive correlation with posterior K average. This correlation between HIL and the change in posterior K average is arguably the most clinically valuable finding of our study, as it allows for the reliable prediction of the most significant power change affecting subsequent IOL power calculation. We also identified a clinically relevant threshold of HIL that significantly affects PCC, suggesting this cutoff to be approximately 3.5

mm. This finding aligns with previous studies that suggested an HIL exceeding 3.5 mm is significantly correlated with refractive errors [19]. Minami et al. [20] demonstrated that larger pterygium extension, exceeding approximately 25% of the corneal diameter (about 3 mm), is associated with increased total corneal higher order aberrations after surgery. Therefore, our identification of an HIL cutoff of 3.5 mm as clinically relevant is broadly consistent with these reports and may represent an early threshold before more severe corneal optical distortions, including those affecting the posterior corneal surface, occur.

The postoperative duration showed no statistically significant correlation with the perioperative change of posterior K average or posterior flat K. Unlike the anterior cornea, which may take 1 to 12 months to stabilize depending on the size of the pterygium before definitive cataract surgery [21], PCC changes did not show a time-dependent pattern in our dataset. However, given the retrospective design and variable follow-up intervals, the exact time course of PCC changes cannot be determined. Therefore, while the data suggest that measurable changes in the posterior cornea occur after pterygium excision, it cannot be concluded whether these changes happen immediately or gradually, or whether they reach a stable state at a specific postoperative time. It should be noted that the lack of correlation in a cross-sectional analysis does not guarantee longitudinal stability. Future longitudinal studies with multiple early postoperative measurements are needed to clarify the dynamics of PCC change. Additionally, the HIL cutoff of 3.5 mm was suggested based on subgroup comparisons at 0.5 mm intervals rather than receiver operating characteristic curve analysis. Therefore, this value should be interpreted as a clinical guide rather than an absolute statistical threshold. Furthermore, as this study was conducted at a single center with a specific ethnic population, the applicability of the 3.5 mm HIL threshold to broader clinical settings or other ethnic groups requires further validation through large-scale, multicenter studies.

Another limitation is that we did not quantify the direct impact of PCC changes on IOL power prediction errors or perform ray-tracing simulations. Although the mean change in the posterior K average was statistically significant, the absolute magnitude (approximately 0.05 D) suggests that the resultant refractive shift might be subtle in routine cases. Future studies incorporating total keratometry IOL formulas are warranted to determine the exact re-

fractive implications of these posterior corneal changes.

In conclusion, pterygium excision induces significant posterior corneal flattening, with the magnitude proportional to HIL, while showing no significant correlation with postoperative duration in this cohort. The HIL value of 3.5 mm was identified as a clinically relevant cutoff. Although the refractive impact may be subtle in routine cases, surgeons should be aware of these posterior corneal changes as a consistent response, especially in eyes with HIL ≥ 3.5 mm.

Conflicts of Interest: None.

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