

Effect of Subepithelial Pterygium Pedicle Length on Anterior Corneal Keratometry and Wavefront Aberrations

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Purpose: To introduce subepithelial pterygium pedicle (SPP) and to investigate the effect of SPP length on the anterior corneal curvature including keratometry and aberrations.

Methods: In this single-center retrospective cohort, 72 eyes of 72 patients with primary nasal pterygium were analyzed using anterior segment (AS) swept-source optical coherence tomography (SS-OCT; Anterior). We evaluated SPP length, horizontal invasion length (HIL), and corneal profiles including keratometry, root mean square values for lower- and higher-order aberrations, and first- to fourth-order wavefront aberrations. Correlations between SPP length and these parameters were assessed after adjusting for HIL. The SPP cutoff for significant anterior horizontal tilt deterioration was determined using receiver operating characteristic (ROC) analysis and validated by analysis of covariance controlling for HIL.

Results: SPP was detected in 57 of 72 eyes (79.2%), with a mean length of $842.3 \pm 408.1 \mu\text{m}$. A significant positive correlation was found between SPP length and HIL ($r = 0.376$, $p = 0.001$). After adjusting for HIL, SPP length remained significantly associated with anterior corneal horizontal tilt ($p = 0.026$), whereas no significant correlations were observed with other refractive or aberration parameters. ROC curve analysis identified an SPP length of approximately $850 \mu\text{m}$ as the threshold for predicting anterior horizontal tilt $\geq 3.65 \mu\text{m}$. Consequently, this cutoff significantly differentiated subgroups after adjusting for HIL, showing a marked increase in horizontal tilt in eyes with SPP $\geq 850 \mu\text{m}$ ($p = 0.016$), indicating mechanical distortion.

Conclusions: SPP length, a subepithelial microstructural parameter visualized by AS SS-OCT, independently correlates with anterior horizontal tilt after adjustment for HIL. This finding suggests that SPP length serves as a microstructural indicator of horizontal mechanical corneal distortion in eyes with pterygium.

Key Words: Anterior, Corneal wavefront aberration, Horizontal tilt, Keratometry, Pterygium

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Pterygium is characterized by conjunctival fibrovascular growth extending onto the cornea, where it consequently distorts the anterior corneal surface [1]. As the lesion advances over the cornea, it creates localized surface irregularities and alters the corneal curvature, thereby increasing astigmatism and various wavefront aberrations [2–4]. Such optical changes can reduce visual quality and this may oc-

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cur even when refractive error itself is relatively small [5]. Recent studies have demonstrated that the degree of corneal optical distortion correlates with the morphological parameters of the pterygium, such as its size, thickness, and the horizontal invasion length (HIL) of pterygium, representing the extent of corneal invasion [6,7]. Understanding the early morphological changes that precede these optical deteriorations is crucial for timely intervention and accurate prediction of visual outcomes.

Recent advances in anterior segment (AS) swept-source optical coherence tomography (SS-OCT) have enabled high-resolution visualization of the pterygium-cornea junction, overcoming the resolution limitations of conventional optical coherence tomography or Scheimpflug camera-based imaging [2,8]. This technology allows for the precise identification of microstructural changes at the interface between corneal stroma and the pterygium head. Through this enhanced visualization, we observed a linear,

subepithelial hyperreflective structure originating at the distal epithelial edge of the pterygium head and extending further beneath the corneal epithelium. We have termed this structure the “subepithelial pterygium pedicle (SPP)” (Fig. 1). While clinicians may have empirically observed this subepithelial extension during surgical excision, it has neither been formally named nor quantitatively analyzed in previous literature. Therefore, this study aims to introduce the concept of the SPP, quantify its length using AS SS-OCT, and evaluate its independent effect on anterior corneal curvature and aberrations.

Materials and Methods

Ethics statement

The research protocol received approval from the Chung-

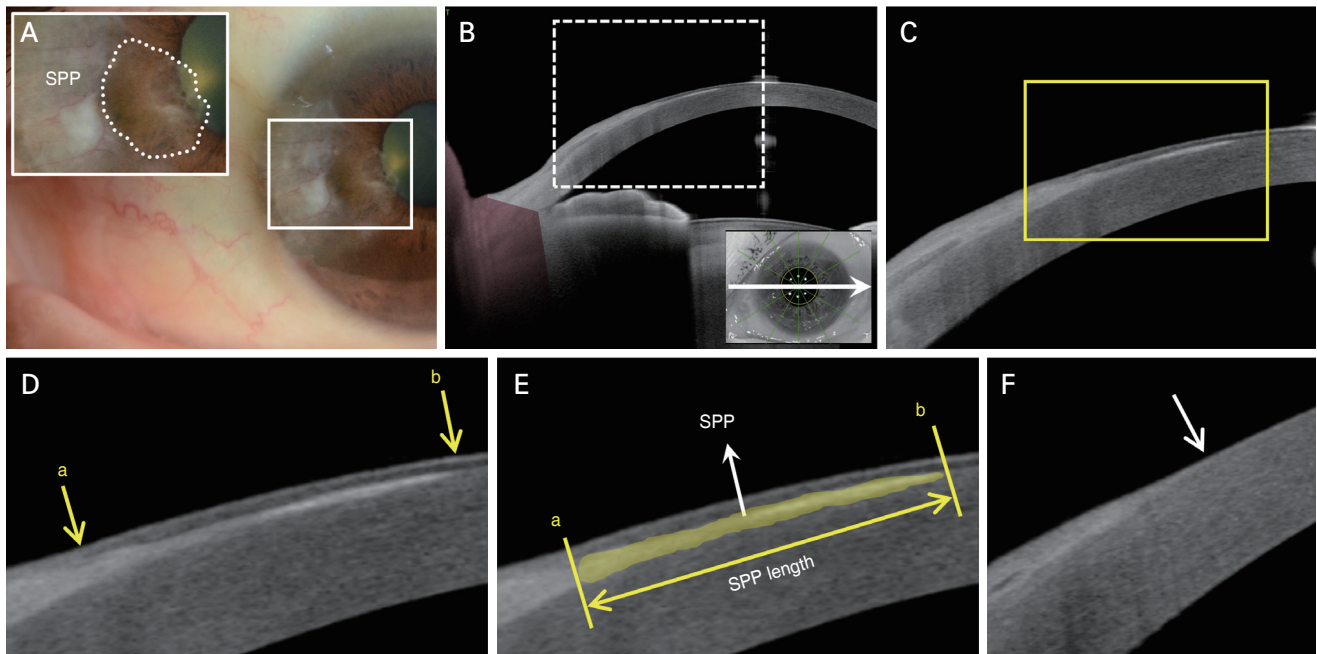


Fig. 1. Representative photographs and measurement steps of subepithelial pterygium pedicle (SPP). (A) Morphology of the SPP observed using slit-lamp biomicroscopy. A faint area arising from the leading edge of the pterygium head is noted (dotted outline). (B) Anterior segment (AS) swept-source optical coherence tomography (SS-OCT; Anterior) B-scan image acquired using the Metrics App. The white dashed box indicates the pterygium head magnified in (C) to verify the SPP. The inset (bottom right) shows the infrared *en face* view with fixed radial scan lines (green); the white arrow indicates the horizontal meridian (0° to 180°) selected for analysis, which aligns with the central longitudinal axis of the pterygium. (C) Magnified view of the pterygium head as the region. The yellow box indicates the region of interest (ROI) shown in (D), where the SPP starts and extends distally. (D) High-magnification view of the ROI. Arrow a indicates the epithelial edge of the pterygium head, which corresponds to the proximal starting point. Arrow b indicates the distal end point where the linear high-signal SPP terminates. (E) Measurement of SPP length. The SPP structure is highlighted in yellow. The length was defined as the distance between the two virtual lines corresponding to points a and b. (F) Representative AS SS-OCT image of a pterygium without SPP. Unlike the SPP group, the subepithelial structure emanating from the epithelial end of the pterygium head (arrow) is absent.

Ang University Hospital Institutional Review Board (No. 2510-007-19596). The requirement for informed consent was waived due to the use of deidentified data and the retrospective nature of the study. The entire process followed the Declaration of Helsinki principles.

Study design and subjects

This study was designed as a single-center retrospective cohort based on review of clinical chart records. This study included 72 eyes from 72 patients with primary nasal-only pterygium which was evaluated using AS SS-OCT (Anterior, Heidelberg Engineering) between September 2021 and June 2023. Patients with double-headed pterygium, isolated temporal pterygium or recurrent pterygium were excluded, as were those with a history of corneal refractive surgery. To ensure statistical independence, for patients presenting with bilateral pterygium, one eye was randomly selected for analysis.

Study protocol

This study was performed as follows: (1) data acquisition: measurement of anterior keratometry and anterior corneal aberration values using AS SS-OCT; (2) morphologic analysis (quantification of the HIL of the pterygium and SPP length using AS SS-OCT images); (3) intergroup comparison (group 1, demographics and pterygium severity between the non-SPP group vs. group 2, the SPP group); (4) correlation analysis (evaluation of the impact of SPP length adjusted for HIL on the anterior corneal keratometry and aberrations); and (5) cutoff determination (identification of the SPP length cutoff value associated with significant deterioration in anterior corneal aberration by receiver operating characteristic [ROC] analysis).

Clinical severity grading

All eyes with pterygium were graded for clinical severity based on the T grades, which considers the translucency of the pterygium body stroma [1]. T grading system classifies pterygium as follows: T1 with clearly visible underlying episcleral vessels, T2 with episcleral vessels partially covered by the pterygium body, and T3 with episcleral vessels completely covered by the pterygium body.

Anterior corneal keratometry and wavefront aberrations based on AS SS-OCT

Using AS SS-OCT, the anterior simulated keratometry (Sim K) average was measured at the 3-mm ring. Anterior corneal wavefront aberration parameters, including root mean square (RMS) lower-order aberration (LoA), RMS higher-order aberration (HoA) and first- to fourth-order individual aberrations, including vertical and horizontal tilt, defocus, oblique and the ratio of with the rule (WTR) to against the rule (ATR) astigmatism, oblique trefoil, vertical and horizontal coma, horizontal trefoil and spherical aberration, were analyzed within a 6-mm diameter anterior corneal zone.

Measurement of HIL and SPP length based on AS SS-OCT

HIL and SPP length were measured in images from the Metrics App in AS SS-OCT. The Metrics App acquires radial B-scans at fixed meridians (e.g., 0°, 30°, 60°, 90°, 120°, and 150°). Although the device's Imaging App permits free meridian adjustment, it does not support the specific quantitative measurement tools required for this analysis. Therefore, to ensure standardized quantification, we utilized the Metrics App and selected the radial B-scan that most closely aligned with the central longitudinal axis of the pterygium (typically 0°, 30°, or 150° meridian) to capture the maximal extent of HIL and SPP.

HIL was measured as the horizontal linear distance representing the extent of pterygium invasion onto the cornea, defined from a tangent reference line at the limbal surface to the advancing edge of the pterygium head, in accordance with previously described methods [6,7,9]. SPP was defined as a linear subepithelial hyperreflective structure that originates at the distal epithelial edge of the pterygium head and extends further beneath the corneal epithelium as seen in both slit-lamp biomicroscopy (Fig. 1A) and AS SS-OCT (Fig. 1B). The SPP length was measured on the image that best delineated the pterygium morphology, using the Metrics App of the AS SS-OCT. To clarify the measurement protocol, a step-by-step illustration is provided in Fig. 1C–1E. We verified the SPP by magnifying the pterygium head (Fig. 1C) and identifying the region of interest where the SPP starts and extends distally (Fig. 1D). The measurement landmarks were defined based on tomo-

graphic features: the proximal start point (arrow a) corresponds to the epithelial edge of the pterygium head, and the distal end point (arrow b) corresponds to the termination of the linear high-signal SPP (Fig. 1D). The SPP length was measured as the perpendicular distance between two virtual reference lines passing through these points (Fig. 1E). For comparison, a representative optical coherence tomography image of a pterygium without SPP is shown in Fig. 1F, where the white arrow indicates the absence of the subepithelial structure emanating from the epithelial end. All SPP length values were measured by a single experienced examiner (KWK).

Statistical analysis

All statistical analyses were performed with Prism ver. 10 (GraphPad). Parametric or nonparametric tests were selected based on the normality of the data distribution. Comparisons between groups classified according to the presence of SPP were performed using the Student *t*-test and chi-square test. The correlation between HIL and SPP length was assessed with Spearman rank correlation test. To evaluate the correlation of SPP length adjusted for HIL with anterior corneal keratometry and wavefront aberrations, a partial correlation analysis was conducted while controlling for the effect of HIL. To determine the cutoff value of SPP length for predicting significant anterior corneal horizontal tilt, ROC curve analysis was performed. The Youden Index (sensitivity + specificity – 1) was calculated to identify the threshold that maximizes the combined sensitivity and specificity. Finally, analysis of covariance (ANCOVA) was performed with HIL as a covariate to compare subgroups divided by the cutoff value of SPP length. All values were expressed as mean $\pm$ standard deviation, and statistical significance was defined as *p*-value of < 0.05 .

Results

Demographic and clinical characteristics of pterygium

A total of 72 eyes from 72 subjects with primary nasal pterygium were included in this study. Table 1 presents the demographic information and clinical profiles of subjects with pterygium. The subjects consisted of 34 men (47.2%)

Table 1. Demographic and clinical characteristics of subjects with pterygium

Characteristic	Value
No. of subjects	72
No. of eyes	72
Age (yr)	59.5 $\pm$ 11.9
Sex	
Female	38 (52.8)
Male	34 (47.2)
T grade	
T1	21 (29.2)
T2	40 (55.6)
T3	11 (15.3)
HIL (mm)	4.16 $\pm$ 1.41

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

HIL = horizontal invasion length.

and 38 women (52.8%), with an mean age of 59.5 $\pm$ 11.9 years. In terms of the T grade classification, 21 eyes (29.2%) were classified as T1, 40 eyes (55.6%) as T2, and 11 eyes (15.3%) as T3. The mean HIL was 4.16 $\pm$ 1.41 mm.

Comparison of baseline characteristics between the groups with and without SPP

The subjects were classified into two groups based on the presence of SPP, group 1 (without SPP) and group 2 (with SPP). In group 2, where SPP was identified on AS SS-OCT, the mean SPP length was 842.3 $\pm$ 408.1 μ m (Table 2). The proportion of female patients was 26.7% in group 1 and 59.6% in group 2, which showed a statistically difference ($p = 0.023$). The mean HIL was 3.37 $\pm$ 1.64 mm in group 1. This value was significantly lower than that in group 2, where the corresponding value was 4.37 $\pm$ 1.28 mm ($p = 0.014$). However, no significant differences were observed between the two groups in terms of mean age or T grade ($p = 0.247$ and $p = 0.925$, respectively).

Correlation of SPP length with HIL, anterior corneal keratometry, and wavefront aberrations

There was a statistically significant positive correlation between HIL and SPP length ($r = 0.376$, $p = 0.001$). Consequently, we analyzed the correlation between SPP length

Table 2. Demographics and clinical characteristics of pterygium with and without SPP

Variable	Group 1 (without SPP)	Group 2 (with SPP)	<i>p</i> -value
No. of subjects	15	57	-
No. of eyes	15	57	-
Length of SPP (μm)	0	842.3 ± 408.1	-
Sex*			0.023 [†]
Female	4 (26.7)	34 (59.6)	
Male	11 (73.3)	23 (40.4)	
Age (yr) [‡]	56.3 ± 11.6	60.4 ± 12.0	0.247
T grade*			0.925
T1	4 (26.7)	17 (29.8)	
T2	9 (60.0)	31 (54.4)	
T3	2 (13.3)	9 (15.8)	
HIL (mm) [‡]	3.37 ± 1.64	4.37 ± 1.28	0.014 [†]

Values are presented as number only, mean ± standard deviation, or number (%).

SPP = subepithelial pterygium pedicle; HIL = horizontal invasion length.

*Chi-square test; [†]*p* < 0.05; [‡]Student *t*-test.

Table 3. Correlation of SPP length with anterior swept-source optical coherence tomography-based anterior corneal keratometry and anterior corneal wavefront aberrations before and after adjustment for HIL

Variable	SPP length (unadjusted for HIL)*		SPP length (adjusted for HIL) [†]	
	<i>r</i>	<i>p</i> -value	<i>r</i>	<i>p</i> -value
Anterior Sim K average (D)	-0.203	0.088	-0.045	0.707
Anterior corneal RMS value				
RMS LoA (μm)	0.402	<0.001 [‡]	0.187	0.118
RMS HoA (μm)	0.325	0.005 [‡]	0.053	0.660
Absolute magnitude of anterior corneal Zernike coefficient (μm)				
First-order aberration				
Vertical tilt	0.022	0.854	0.029	0.807
Horizontal tilt	0.382	<0.001 [‡]	0.265	0.026 [‡]
Second-order aberration				
Oblique astigmatism	0.375	0.001 [‡]	0.209	0.080
Defocus	-0.895	0.455	0.091	0.448
WTR/ATR astigmatism	0.332	0.004 [‡]	0.079	0.513
Third-order aberration				
Oblique trefoil	0.378	0.001 [‡]	0.145	0.226
Vertical coma	0.019	0.872	-0.016	0.894
Horizontal coma	0.365	0.002 [‡]	0.203	0.090
Horizontal trefoil	0.267	0.024 [‡]	-0.095	0.433
Fourth-order aberration				
Spherical aberration	-0.175	0.142	-0.140	0.246

SPP = subepithelial pterygium pedicle; HIL = horizontal invasion length; Sim K = simulated keratometry; RMS = root mean square; LoA = lower-order aberration; HoA = higher-order aberration; WTR/ATR = with the rule to against the rule ratio.

*Spearman correlation test; [†]Partial correlation test while controlling HIL; [‡]*p* < 0.05.

and anterior corneal refractive and aberration profiles both before and after controlling for HIL to investigate the SPP-specific effect.

In the unadjusted analysis, SPP length showed significant positive correlations with multiple parameters, including RMS LoA, RMS HoA, horizontal tilt, oblique astigmatism, WTR/ATR astigmatism, oblique trefoil, horizontal coma, and horizontal trefoil (Table 3). However, after controlling for HIL, most of these associations lost statistical significance. Notably, the anterior horizontal tilt remained significantly correlated with SPP length even after adjustment ($p = 0.026$). In contrast, no significant correlations were observed between SPP length and anterior Sim K or other wavefront aberration profiles (Table 3).

Determination of the cutoff value of SPP length for anterior horizontal tilt

Given that anterior horizontal tilt was the only parameter significantly correlated with SPP length after controlling for HIL, we next sought to identify the SPP length cutoff value that best discriminates anterior corneal horizontal tilt (Table 3). First, we analyzed the distribution of horizontal tilt values across the entire study cohort and identified that the threshold for the upper quartile (top

25%) was 3.65 μm . Accordingly, we performed ROC curve analyses to determine the SPP length cutoff for predicting horizontal tilt values $\geq 3.65 \mu\text{m}$.

For predicting horizontal tilt $\geq 3.65 \mu\text{m}$, the area under curve was 0.740 (95% confidence interval [CI], 0.604–0.875; $p = 0.002$) (Table 4). An SPP length cutoff of $>635.5 \mu\text{m}$ yielded a Youden J index of 0.3889, with a sensitivity of 83.3% and specificity of 55.6%. Alternatively, a cutoff of $>853.0 \mu\text{m}$ showed the same Youden J index (0.3889) but provided a lower sensitivity (55.6%) but better specificity (83.3%), indicating a trade-off for clinical screening. Since lower specificity implies a higher rate of false positives, where significant tilt might be driven by factors other than SPP, we prioritized high specificity to define a distinct phenotype of subepithelial invasion. Then, considering that the cutoff of approximately 853 μm consistently demonstrated the best predictive performance or balance across both thresholds, we selected 850 μm as the final cutoff, approximating the statistical threshold of 853 μm for clinical practicality.

Table 5 presents the results of the ANCOVA, performed with HIL as a covariate, to compare the estimated marginal means of anterior corneal horizontal tilt between subgroups stratified by this 850 μm cutoff. A statistically significant difference was observed between the subgroups

Table 4. Receiver operating characteristic curve analysis of SPP length for predicting anterior corneal horizontal tilt $\geq 3.65 \mu\text{m}$

Outcome	AUC	95% CI	<i>p</i> -value	Cutoff of SPP length (μm)	Sensitivity (%)	Specificity (%)	Youden J
Horizontal tilt $\geq 3.65 \mu\text{m}$	0.740	0.604–0.875	0.002	>629.0	83.3	53.7	0.3703
				>635.5	83.3	55.6	0.3889
				>835.5	55.6	81.5	0.3704
				>853.0	55.6	83.3	0.3889
				$>1,115.0$	44.4	94.7	0.3888

SPP = subepithelial pterygium pedicle; AUC = area under curve; CI = confidence interval.

Table 5. Comparison of anterior horizontal tilt according to cutoff values of SPP length with adjustment for HIL

SPP length cutoff (μm)	No. of eyes	Anterior corneal horizontal tilt (μm)	Adjusted for preoperative HIL			
			Estimated marginal	F	<i>p</i> -value	Partial η^2
<850	53	1.81 ± 1.85	2.01 ± 0.25	6.051	0.016*	0.081
≥ 850	19	3.75 ± 2.52	3.22 ± 0.42			

Analysis of covariance was used. Anterior corneal horizontal tilt values are presented as mean $\pm$ standard deviation and estimated marginal values are presented as mean $\pm$ standard error.

SPP = subepithelial pterygium pedicle; HIL = horizontal invasion length.

* $p < 0.05$.

($F = 6.051$, $p = 0.016$). The unadjusted mean horizontal tilt values were $1.81 \pm 1.85 \mu\text{m}$ for the SPP $<850 \mu\text{m}$ group and $3.75 \pm 2.52 \mu\text{m}$ for the SPP $\geq 850 \mu\text{m}$ group. After adjusting for HIL, the estimated marginal means remained significantly distinct at 2.01 ± 0.25 and $3.22 \pm 0.42 \mu\text{m}$, respectively.

Discussion

Previous studies have demonstrated that morphological profiles such as pterygium size, thickness, and HIL influence anterior corneal astigmatism, irregularity and aberrations [2,3,6,10]. In this study, we identified a previously unreported subepithelial hyperreflective structure from the pterygium head, which we termed as SPP, using AS SS-OCT. This region represents a subepithelial microstructure of the pterygium, and we aimed to investigate this microstructure in detail and revealed its influence on the anterior corneal aberration, especially anterior horizontal tilt.

Ha and Kim [6] examined several morphometric profiles including HIL, height, thickness and residual corneal thickness/central corneal thickness to analyze the optical impact of pterygium and to predict surgical outcomes, identifying HIL as a key morphological determinant of AS distortion. Similarly, previous studies also demonstrated that horizontal or relative invasion length significantly correlates with corneal astigmatism and HoA [11,12]. However, these studies focused primarily on surface level morphology and did not assess the underlying subepithelial microstructures. In contrast, our study expands the analytical scope to the microstructural level, linking subepithelial morphology with optical aberrations thus deepening the pathophysiological understanding of pterygium induced visual distortion.

In the group analysis, HIL was significantly greater in group 2 (with SPP) than in group 1 (without SPP), and the sex-ratio difference likely reflects a sampling artifact due to the limited number of cases. A significant positive correlation between HIL and SPP length further suggests that both parameters represent markers of a shared fibrovascular proliferative pathway. To determine whether SPP represents a secondary by-product of HIL or an independent contributor to corneal distortion, we evaluated the relationships between SPP length and anterior corneal profiles while adjusting for HIL. Using ANCOVA with HIL as a

covariate, SPP length remained significantly correlated with anterior horizontal tilt. Horizontal tilt, measured by AS SS-OCT, quantifies the degree of wavefront tilt in the horizontal direction and represents one of the anterior corneal wavefront aberration components. As a first-order Zernike term, horizontal tilt is categorized within LoA. Clinically, horizontal tilt reflects a deviation of the optical axis from the visual axis in the horizontal direction [13]. Although tilt is a LoA that can theoretically be corrected with spectacles, in the context of pterygium, excessive horizontal tilt signifies a gross asymmetric mechanical distortion. While this may not permanently limit visual potential like HoAs, it serves as a critical surgical indicator. A high tilt value suggests that the SPP is exerting significant traction. Therefore, identifying this change preoperatively may suggest the need for a more extensive subepithelial dissection to potentially release this mechanical stress. Mechanistically, we hypothesize that the SPP acts as a subepithelial fibrous anchor exerting tractional stress. Since the pterygium progresses horizontally, this tension vector is aligned with the horizontal meridian. Consequently, the SPP induces specific asymmetric flattening that manifests as horizontal tilt, while the vertical meridian remains relatively unaffected due to the lack of vertical tractional forces.

Among the cutoff values assessed, an SPP length of $850 \mu\text{m}$ most clearly distinguished the subgroups with respect to anterior horizontal tilt. Importantly, this difference remained significant even after adjusting for HIL. Patients with an SPP length $\geq 850 \mu\text{m}$ exhibited significantly greater horizontal tilt values, suggesting that beyond this threshold, subepithelial invasion exerts a mechanical distortion on the optical axis independent of the superficial pterygium size. Conversely, if the SPP is shorter than $850 \mu\text{m}$, its capacity to induce corneal tilt appears limited. Thus, $850 \mu\text{m}$ may represent a critical microstructural cutoff for monitoring optical degradation in pterygium progression.

It is noteworthy that pterygium invasion often extends into the 6-mm wavefront analysis zone, potentially confounding aberration measurements. However, by treating HIL as a covariate in our statistical models, we adjusted for the direct optical effect of the pterygium mass. The persistence of a significant correlation between SPP and horizontal tilt after this adjustment supports the hypothesis that the SPP contributes a distinct tractional component beyond the mere physical presence of the lesion.

From a surgeon's perspective, after removing the epithe-

lium over the pterygium head, the subjacent SPP embedded within the underlying tissue can be identified. Based on our finding that SPP length correlates with mechanical tilt, we hypothesize that incomplete removal of this structure could theoretically allow residual tethering forces to persist. As current pterygium surgery emphasizes micro-level anatomical dissection [14,15], the SPP may represent a relevant target for dissection to release this traction. However, it is important to note that this study did not evaluate postoperative outcomes. Therefore, while we suggest that more extensive dissection in eyes with SPP ≥ 850 μm might be beneficial to relieve mechanical stress, future longitudinal studies are required to confirm whether complete SPP excision actually translates to improved refractive stability or reduced recurrence.

This study has several limitations. First, SPP identification and length measurements were performed manually, which may inherently result in observer variability and potentially compromise reproducibility. While this limitation could be overcome in future studies by implementing interobserver and intraobserver variability assessments or using automated segmentation with quantitative validation tools, we strengthened measurement reliability in the present study by having all data collected by a single experienced examiner to minimize intraobserver variation. Second, due to the retrospective design, baseline anterior corneal keratometry and wavefront aberration data prior to pterygium development were unavailable. Furthermore, this study focused on preoperative morphological-optical correlations and did not assess postoperative outcomes. Thus, we could not provide direct evidence linking SPP removal to surgical prognosis, which remains a subject for future investigation. Consequently, direct prepterygium and postpterygium comparisons could not be performed, which limits the ability to determine the precise extent to which SPP alone contributed to anterior optical changes.

Another limitation is the lack of direct histopathological correlation. Due to the retrospective design and the tendency for delicate SPP tissue to distort during peeling, obtaining intact specimens for histological analysis was not feasible. Consequently, the SPP should be interpreted as a tomographic imaging biomarker of subepithelial invasion rather than a definitive histological entity. Future prospective studies are needed to clarify its precise cellular composition. Nevertheless, this study is the first to quantitatively evaluate subepithelial morphology using AS SS-

OCT and to objectively establish the association between SPP and anterior corneal aberrations, thereby providing novel insights into the microstructural-optical interplay in pterygium.

In addition, it should be noted that the standard deviations for wavefront aberration metrics were relatively large compared to the means. This variability reflects the heterogeneous nature of pterygium morphology and individual differences in corneal biomechanical response. However, the fact that significant correlations and group differences were observed despite this variability reinforces the robustness of the association between SPP length and anterior corneal distortion.

In conclusion, this study demonstrates that SPP length independently correlates with anterior horizontal tilt after adjusting for HIL, identifying it as a significant tomographic biomarker of subepithelial invasion. Rather than merely affecting refractive error, SPP length may serve as a practical surgical indicator for predicting mechanical corneal distortion, suggesting the potential clinical value of identifying this tethering tissue during pterygium excision.

Conflicts of Interest: None.

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