

Association between Fibrovascular Translucency of Pterygium and Corneal Curvature and Aberrations after Adjustment for Horizontal Invasion Length

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Purpose: This study aims to determine whether the translucency-based clinical grade of pterygium shows independent relationships with anterior and posterior corneal curvature and anterior wavefront aberrations, with adjustment for horizontal invasion length (HIL) measured by anterior segment (AS) swept-source optical coherence tomography (SS-OCT).

Methods: This study involved 53 eyes from 51 patients diagnosed with primary nasal pterygium. The clinical grade of the pterygium was evaluated using T grade based on the fibrovascular translucency. AS SS-OCT (Anterior, Heidelberg Engineering) provided HIL (in millimeters), thickness (in micrometers), anterior/posterior keratometry at the 3.0-mm ring, and anterior corneal wavefront metrics within a 6.0-mm zone. The device was also used to evaluate the magnitudes for the individual first- to fourth-order aberrations of the anterior corneal fields. Also, the fourth- to seventh-order root mean square (RMS), RMS lower-order aberration (LoA), and RMS higher-order aberration (HoA) values were collected. For statistical analysis, Spearman rank correlation test and Pearson correlation test were performed, along with partial correlation test adjusted for HIL.

Results: The mean age of subjects was 59.3 ± 11.4 years, and 51.0% were female. T grade correlated positively with HIL. HIL showed strong associations with anterior simulated keratometry (Sim K) average, anterior Sim K steep, anterior Sim K flat, and anterior corneal astigmatism—but not with posterior corneal parameters. HIL also showed significant correlations with multiple anterior corneal wavefront parameters. After adjustment for HIL, T grade remained independently correlated with anterior Sim K flat, RMS LoA, and defocus; no significant relationships were observed with other Zernike terms or posterior metrics. Additionally, T grade was positively correlated with pterygium thickness.

Conclusions: T grade adds independent, complementary information (associations with flat keratometry, LoA RMS, and defocus) even after controlling for HIL. Incorporating T grade into preoperative assessment may improve estimation of optical burden and surgical prognosis.

Key Words: Anterior-segment optical coherence tomography, Anterior-segment swept-source optical coherence tomography, Corneal curvature, Pterygium

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Pterygium, a common ocular surface disorder, is characterized by the extension of abnormal fibrovascular conjunctival tissue from the limbus to the central cornea [1]. Pterygium is clinically significant because it induces corneal astigmatism, anterior surface irregularity, and higher-order aberrations (HoAs) [2], thereby degrading visual quality by distorting the anterior corneal surface. Alterations of the anterior corneal surface caused by pterygium can lead to degradation of the vision quality as the anterior corneal surface is the principal refractive interface of the eye and the primary determinant of retinal image quality [3].

Accurate evaluation of clinical severity is crucial for pterygium treatment planning, outcome prediction, and standardized communication. Among various grading systems, Tan grading system (T grade), introduced by Tan et al. [4], remains the most widely applied, providing a simple slit-lamp–based assessment of fibrovascular opacity with proven clinical validity. T grade is convenient for clinical use but relies on subjective visual assessment under slit-lamp examination. As a result, the evaluation may vary depending on the examiner's experience or illumination and does not provide information on the actual tissue thickness or depth of corneal invasion. Separately, anterior segment (AS) swept-source optical coherence tomography (SS-OCT) has enabled quantitative evaluation of pterygium morphology and its optical impact through parameters such as horizontal invasion length (HIL), thickness, corneal refractive profiles, and wavefront aberrations [5–7]. This imaging modality can provide an objective complement to the clinically practical but qualitative T grade. Because the degree of translucency is thought to reflect fibrovascular proliferation within the pterygium, correlating T grade with quantitative AS SS-OCT parameters may clarify whether the clinical grading truly represents the underlying structural characteristics. Investigations into this relationship may suggest different structural aspects of pterygium, including its morphology and underlying tissue characteristics. However, no prior study has compared T grade with objective AS SS-OCT–derived parameters, and the relationship between traditional qualitative grading and new quantitative AS SS-OCT findings remains uncertain.

In this regard, our study investigated whether T grade demonstrates independent relationships with anterior corneal curvature and wavefront aberrations after adjusting

for HIL. Through this comprehensive analysis, we ultimately aim to provide new insights into the pathophysiological relevance of T grade and bridge traditional clinical grading with modern imaging-based metrics.

Materials and Methods

Ethics statement

This research protocol was approved by the Institutional Review Board of Chung-Ang University Hospital (No. 2509-017-19594). The requirement for informed consent was waived due to the use of deidentified data and the retrospective nature of the study. The authors did not have access to information that could identify individual participants during or after data collection. In our outpatient clinics, we thoroughly assessed each pterygium patient with a standardized protocol. All study procedures adhered to the principles of the Declaration of Helsinki.

Subjects

This study included patients diagnosed with nasal-only primary pterygium that underwent examination with AS SS-OCT (Anterion, Heidelberg Engineering) between September 2021 and June 2023. Patients who went through corneal refractive surgeries were excluded from the study.

Study design

This study was a retrospective, single-center longitudinal cohort study. First, we reviewed the medical charts of selected patient group according to the inclusion criteria. Using the AS SS-OCT, we retrospectively evaluated the HIL and thickness of pterygium, anterior and posterior corneal refractive profiles, and anterior corneal wavefront parameters. Correlation analysis of HIL and T grades of pterygium with AS SS-OCT–based anterior and posterior corneal refractive profiles and anterior corneal wavefront parameters was conducted.

Clinical severity grading of pterygium

All participants underwent a standard eye examination by a board-certified ophthalmologist. Eyes affected by pte-

rygium were assessed using T grade [4]. T grade evaluated the translucency of the pterygium body stroma, and categorized pterygia as follows: T1 denoted pterygia with clearly visible underlying episcleral vessels (atrophic), T2 indicated those with episcleral vessels partially covered by the pterygium body (intermediate), and T3 referred to pterygia with underlying episcleral vessels completely covered by the pterygium body (fleshy). Standard photograph was utilized to apply this grading system. A single experienced ophthalmologist conducted the assessment of each pterygium. Representative clinical photographs showing each T grade are illustrated in Fig. 1A–1E.

Pterygial morphological profiles and corneal optical properties based on AS SS-OCT

Baseline AS SS-OCT measurements were obtained to characterize pterygium morphology, including HIL (in millimeters) and lesion thickness (in micrometers)—quan-

tified according to previously published protocols [5–7]. Fig. 1 shows representative AS SS-OCT images of pterygium cases with short and long HIL. Corneal refractive profiles were obtained with the device's cornea app at the 3.0-mm ring: anterior simulated keratometry (Sim K) average, steep, flat, and corneal astigmatism, as well as posterior K average, steep, flat, and corneal astigmatism. Within a 6.0-mm zone centered on the corneal vertex, root mean square (RMS) lower-order aberration (LoA) and HoA values were also measured. In addition, 10 anterior-corneal Zernike coefficients from first to fourth orders were collected (first order: vertical tilt, horizontal tilt; second order: oblique astigmatism, defocus, with-the-rule [WTR]/against-the-rule [ATR] astigmatism; third order: oblique trefoil, vertical coma, horizontal coma, horizontal trefoil; and fourth order: spherical aberration). The fourth to seventh-order root RMS, RMS LoA, and RMS HoA values were also collected. To mitigate laterality-related sign inversions, first- through fourth-order coefficients were analyzed as

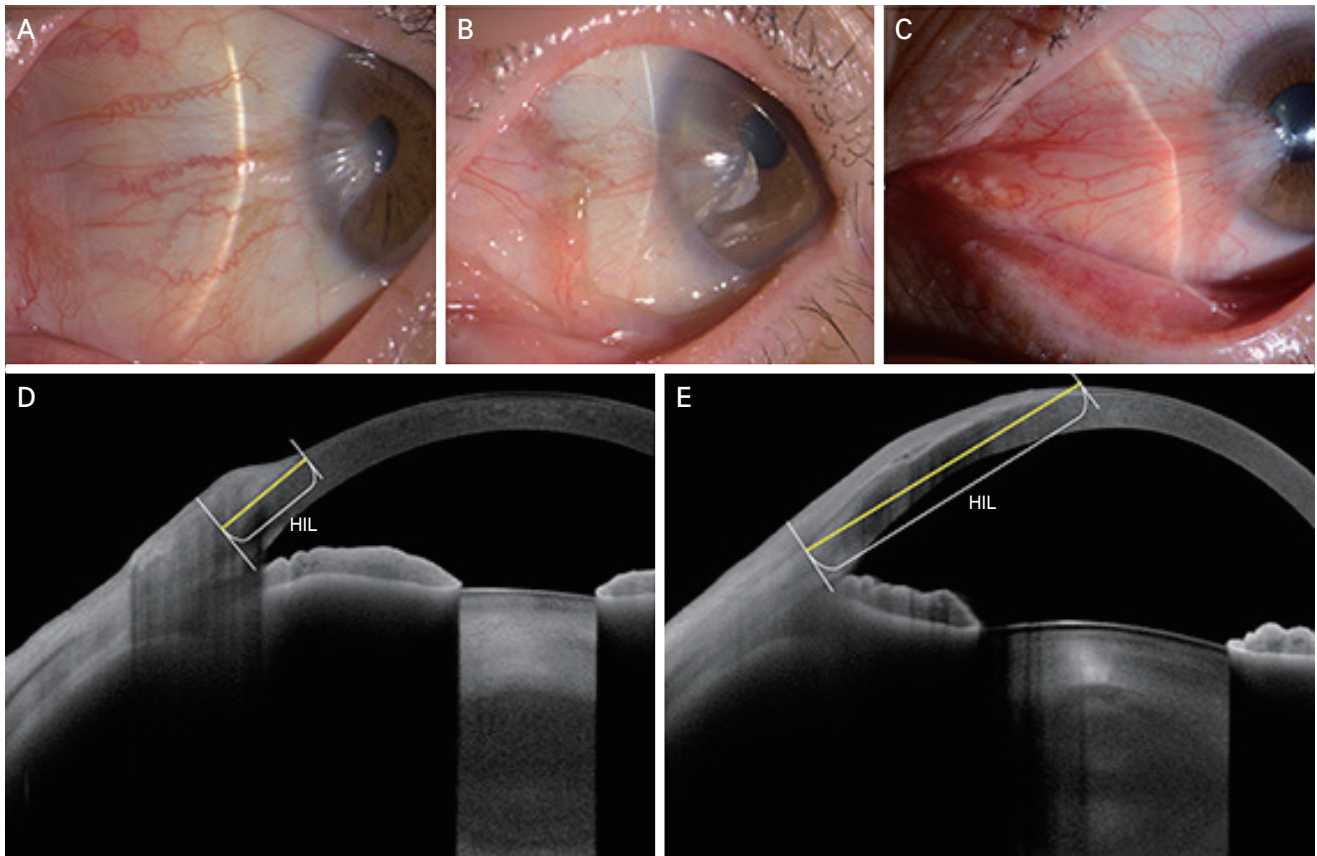


Fig. 1. Representative clinical photographs showing each T grade and anterior segment (AS) swept-source optical coherence tomography (SS-OCT) images of pterygium with short and long horizontal invasion length (HIL). Clinical grading of pterygium: (A) T1, (B) T2, and (C) T3. AS SS-OCT images of pterygium with (D) short and (E) long HIL.

absolute magnitudes (|coefficient|).

Statistical analysis

Statistical analyses were performed using Prism ver. 10.6.1 (GraphPad) and IBM SPSS ver. 30 (IBM Corp). Both nonparametric Spearman rank correlation test and parametric Pearson correlation test were performed. Partial correlation analysis was performed to evaluate the associations among the variables of interest while adjusting for HIL as a potential confounder. The data are presented as mean ± standard deviation, and statistical significance was set at a *p*-value of <0.05.

Table 1. Demographic and clinical characteristics of subjects with pterygium

Variable	Value
No. of patients	51
No. of eyes	53
Age (yr)	59.3 ± 11.4
Sex (n = 51)	
Female	26 (51.0)
Male	25 (49.0)
T grade (n = 53)	
T1	12 (22.6)
T2	32 (60.4)
T3	9 (17.0)
Horizontal invasion length (mm)	4.15 ± 1.38

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

Table 3. Correlation analysis of HIL and T grade of pterygium with anterior segment swept-source optical coherence tomography-based anterior corneal refractive profiles

Variable	HIL (mm)		T grade (adjusted for HIL)	
	r	<i>p</i> -value	r	<i>p</i> -value
Anterior Sim K				
Average	−0.459*	<0.001 [†]	−0.226 [‡]	0.108
Steep	0.440*	0.001 [†]	0.021 [‡]	0.880
Flat	−0.736*	<0.001 [†]	−0.312 [‡]	0.024 [†]
Anterior corneal astigmatism	0.863 [§]	<0.001 [†]	0.273 [‡]	0.051

HIL = horizontal invasion length; Sim K = simulated keratometry.
*Pearson correlation test; [†]Statistically significant (*p* < 0.05); [‡]Spearman rank correlation test; [§]Partial correlation test whilst controlling HIL.

Results

Demographics and baseline data of pterygium

A total of 53 eyes from 51 patients with primary nasal pterygium were included. The mean age was 59.3 ± 11.4 years, and 51.0% of subjects were female. Based on T grade system, 12 eyes (22.6%) were classified as grade 1, 32 eyes (60.4%) as grade 2, and 9 eyes (17.0%) as grade 3. The mean HIL was 4.15 ± 1.38 mm (Table 1).

Correlation between HIL and T grade of pterygium

As shown in Table 2, T grade demonstrated a significant positive correlation with HIL (*r* = 0.459, *p* < 0.001), as determined by Spearman rank correlation test.

Correlation analysis of HIL and T grade of pterygium with anterior and posterior corneal refractive profiles

Correlation analysis demonstrated that HIL was significantly associated with anterior corneal refractive profiles: negative correlations with anterior Sim K average (*r* = −0.459, *p* < 0.001) and Sim K flat (*r* = −0.736, *p* < 0.001), and positive correlations with Sim K steep (*r* = 0.440, *p* = 0.001)

Table 2. Correlation between HIL and T grade of pterygium

	T grade	
	<i>r</i> *	<i>p</i> -value
HIL (mm)	0.459	<0.001 [†]

HIL = horizontal invasion length.
*Spearman rank correlation test; [†]Statistically significant (*p* < 0.05).

and anterior corneal astigmatism ($r = 0.863$, $p < 0.001$). After adjustment for HIL, T grade remained independently correlated with anterior Sim K flat ($r = -0.312$, $p = 0.024$), but not with other anterior indices (Table 3). No significant association was observed between either HIL or T grade and posterior corneal parameters (Table 4).

Correlation analysis of HIL and T grade of pterygium with anterior corneal wavefront parameters

HIL showed significant correlations with multiple anterior corneal wavefront parameters, including RMS LoA, RMS HoA, horizontal tilt, oblique astigmatism, defocus, WTR/ATR astigmatism, oblique trefoil, horizontal coma,

Table 4. Correlation analysis of HIL and T grade of pterygium with anterior segment swept-source optical coherence tomography–based posterior corneal refractive profiles

Variable	HIL (mm)		T grade (adjusted for HIL)	
	r	p-value	r	p-value
Posterior K average	−0.096*	0.493	0.101 [†]	0.478
Posterior steep K	−0.084*	0.552	0.086 [†]	0.542
Posterior flat K	−0.112*	0.423	0.111 [†]	0.433
Posterior corneal astigmatism	0.064 [‡]	0.649	0.195 [‡]	0.166

HIL = horizontal invasion length; K = keratometry.

*Pearson correlation test; [†]Partial correlation test whilst controlling HIL; [‡]Spearman rank correlation test.

Table 5. Correlation analysis of HIL and T grade of pterygium with anterior segment swept-source optical coherence tomography–based anterior corneal wavefront parameters

Variable	HIL (mm)		T grade (adjusted for HIL)	
	r	p-value	r	p-value
RMS value				
RMS LoA	0.860*	<0.001 [†]	0.333 [‡]	0.016 [†]
RMS HoA	0.849*	<0.001 [†]	0.267 [‡]	0.055
Absolute magnitude of Zernike coefficient				
First order aberration				
Vertical tilt	0.139*	0.321	0.224 [‡]	0.110
Horizontal tilt	0.674*	<0.001 [†]	−0.047 [‡]	0.743
Second order aberration				
Oblique astigmatism	0.781*	<0.001 [†]	0.193 [‡]	0.171
Defocus	−0.641 [§]	<0.001 [†]	−0.457 [‡]	<0.001 [†]
WTR/ATR astigmatism	0.851*	<0.001 [†]	−0.270 [‡]	0.053
Third order aberration				
Oblique trefoil	0.734*	<0.001 [†]	0.173 [‡]	0.219
Vertical coma	0.119*	0.398	0.238 [‡]	0.089
Horizontal coma	0.643*	<0.001 [†]	−0.041 [‡]	0.776
Horizontal trefoil	0.816*	<0.001 [†]	−0.144 [‡]	0.309
Fourth corneal aberration				
Spherical aberration	0.210 [§]	0.132	−0.091 [§]	0.523

HIL = horizontal invasion length; RMS = root mean square; LoA = lower-order aberration; HoA = higher-order aberration; WTR = with-the-rule; ATR = against-the-rule.

*Spearman rank correlation test; [†]Statistically significant ($p < 0.05$); [‡]Pearson correlation test; [§]Partial correlation test whilst controlling HIL.

and horizontal trefoil. After controlling for HIL, T grade was independently associated with RMS LoA ($r = 0.333$, $p = 0.016$) and defocus ($r = -0.457$, $p < 0.001$), while no significant relationships were found with other Zernike coefficients (Table 5).

Correlation between T grade and the thickness of pterygium

T grade was positively correlated with pterygium thickness ($r = 0.304$, $p = 0.027$), indicating that less translucent lesions tended to be thicker (Supplementary Table 1).

Discussion

Pterygium is a fibrovascular proliferation from the limbus onto the cornea that degrades visual quality by increasing anterior surface irregularity [8], astigmatism [9], and aberrations [10]. Accurate severity assessment of pterygium is essential for guiding treatment decisions, predicting postoperative visual outcomes, and standardizing communication in clinical and research settings. T grade offers a widely used, qualitative slit-lamp measure of fibrovascular opacity [4]; however, fully objective morphologic and optical characterization has been challenging. With the advent of AS SS-OCT, quantitative indices—HIL, lesion thickness, keratometry, and wavefront metrics—can be measured reproducibly [5–7]. Accordingly, we examined whether the qualitative T grade is associated with these quantitative AS SS-OCT–derived optical parameters, particularly with adjustment for HIL.

Pterygium impairs the optical function of the anterior surface of the cornea [3]. Specifically, pterygium-induced ocular aberrations are closely associated with vision quality [11]. Pterygium-induced HoAs above 3rd order, which cannot be corrected by sphere and cylindrical lenses [12], contribute to dysphotopsia, glare, and reduced contrast sensitivity, ultimately degrading refractive accuracy and image quality [13]. Previous study has further demonstrated that HIL of pterygium is independently associated with increased oblique trefoil/quatrefoil and RMS of fourth-order aberrations, thereby affecting the quality of vision [14].

In our previous studies, we also discovered that HIL thresholds predict perioperative reductions in astigmatism and aberrations after excision [5], and that longer HIL and

higher baseline astigmatism predicted postoperative corneal steep-island formation [6]. In this study, we further confirmed that HIL is one of the important parameters in pterygium evaluation as it is associated with the traditional T grade. This supports HIL as the principal morphological driver of optical quality for pterygium patients, while the T grade can provide complementary information. HIL also showed strong correlations with anterior corneal keratometric indices and corneal astigmatism. These findings align with prior work indicating that anterior surface deformation from pterygial traction is the primary driver of visual disturbance [3,8,10].

For this reason, HIL was selected as the adjustment variable in this study. It represents the geometric extent of corneal involvement—the major structural determinant of optical change—while T grade reflects fibrovascular density and translucency. Adjusting for HIL, thus, allowed evaluation of whether T grade provides additional, independent optical information beyond the invasion length itself.

After adjustment for HIL, T grade remained independently associated with anterior flat keratometry, RMS LoA, and defocus. This finding suggests that, beyond the geometric extent of invasion, the opacity of fibrovascular tissue indicates additional physical forces acting on the cornea. Supplementary analysis further supports this interpretation, as less translucent lesions exhibited greater stromal thickness. Thicker fibrovascular tissue may contain more abundant myofibroblasts and extracellular matrix components, thereby augmenting contractile force and enforcing greater tractional effects on the corneal surface.

Histopathological investigations have consistently demonstrated epithelial hyperplasia and exuberant fibrovascular proliferation within the pterygium stroma, with the extent of such proliferation serving as a reliable morphological index for predicting recurrence after excision [4]. Notably, grade T3 pterygia are associated with a higher risk of recurrence compared with grades T1 and T2, underscoring the clinical validity of T grade as a severity marker [15,16]. The presence of myofibroblasts within fibrovascular tissue provides a convincing explanation for pterygium-induced corneal astigmatism and regional traction. Supporting this concept, previous cellular studies demonstrated marked upregulation of α -SMA expression in stromal fibroblasts derived from severe pterygium cases relative to mild cases, consistent with greater myofibroblast accumulation in more severe cases [16]. These observations

are consistent with previous reports demonstrating that the extent of pterygium invasion is topographically correlated with the degree of WTR corneal astigmatism [17–20]. Collectively, these results support the hypothesis that pterygium-associated astigmatism arises, at least in part, from contractile forces generated by stromal myofibroblasts. These observations highlight fibrovascular translucency not only as a practical clinical grading index but also as a measure to assess both optical degradation and surgical prognosis.

In this study, HIL was associated with most AS parameters measured by AS SS-OCT, whereas the T grade correlated with only a few, including anterior corneal curvature and wavefront aberrations, independent of HIL. These findings suggest that pterygium elongation primarily drives morphological deformation of the corneal surface, while fibrovascular translucency (T grade) represents optical scatter and stromal opacity that contribute independently to image degradation.

Because pterygia have traditionally been evaluated using the T grade, integrating this qualitative grading with the quantitative measurement of HIL allows for a more comprehensive assessment of the lesion's optical impact. Alterations in anterior corneal curvature and wavefront aberrations, associated with either parameter, can lead to decreased contrast sensitivity, glare, and suboptimal postoperative visual recovery. Therefore, concurrent consideration of HIL and T grade may help clinicians determine the optimal timing and surgical approach for excision, as well as estimate postoperative refractive and visual prognosis more accurately.

There are several limitations to this study. The cross-sectional design precludes causal inference between fibrovascular translucency and optical changes. The sample size was relatively small, and histopathologic correlation with fibrovascular density was not available. Future studies incorporating tissue-level analysis and prospective surgical outcomes are needed to validate the hypothesis that lower translucency reflects stronger tractional force.

In conclusion, from a clinical standpoint, the correlations between T grade and with anterior Sim K flat, RMS LoA, and defocus after adjustment indicate that T grade may capture intrinsic optical characteristics of cornea affected by pterygia. Incorporating both HIL and T grade into preoperative assessment may therefore allow for a more nuanced estimation of optical burden and surgical prognosis.

Our study marks a further step in the clinical development utilizing both the traditional T grade and newly devised measurements from AS SS-OCT.

Conflicts of Interest: None.

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Supplementary Materials

Supplementary Table 1. Correlation between T grade and the thickness of pterygium

Supplementary materials are available from <https://doi.org/10.3341/kjo.2025.0152>.

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Supplementary Table 1. Correlation between T grade and the thickness of pterygium

	Thickness of pterygium	
	r	<i>p</i> -value
T grade	0.304*	0.027 [†]

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