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Impact of pterygium morphological profiles on dry eye parameters

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This study aims to determine whether morphological features of pterygium are linked to clinical parameters of dry eye disease. We examined 122 eyes from 109 patients with primary nasal pterygium who underwent preoperative anterior segment swept-source optical coherence tomography (AS SS-OCT, Anterion®, Heidelberg Engineering, Germany) and evaluated dry eye parameters, including the clinical severities of meibomian gland dysfunction, tear osmolarity, Schirmer I, tear matrix metalloproteinase-9 expression, and ocular surface staining. Morphological profiles of pterygium based on AS SS-OCT included horizontal invasion length (HIL), pterygium height, pterygium thickness, and the ratio of residual corneal thickness (RCT) to central corneal thickness (CCT). AS SS-OCT-guided values of anterior corneal astigmatism (ACA) and root mean square (RMS) values of lower-order aberrations (LoA) and higher-order aberrations (HoA) were also obtained. HIL was negatively correlated with corneal erosions and the Sjögren's International Collaborative Clinical Alliance ocular staining score (SICCA OSS). Pterygium height and thickness were positively correlated with tear osmolarity, Schirmer I, and SICCA OSS. Additionally, ACA, corneal RMS LoA and HoA were negatively correlated with corneal erosions and SICCA OSS. Given that HIL inversely correlated with pterygium height and thickness, early pterygium appears to induce desiccation, pterygium surface erosions, and increased reflex lacrimation.

Keywords Aberration, Astigmatism, Dry eye, Morphological profile, Pterygium

Pterygium is a relatively common ocular surface disorder characterized by the anomalous fibrovascular proliferation of subconjunctival tissue onto the corneal surface[1]. Pterygium can cause a range of discomforts in affected individuals, from mild inconveniences to serious morbidities. Typically, this condition can trigger irritation, foreign body sensation, increased lacrimation, cosmetic concerns, and visual disturbance. In real clinical settings, individuals with pterygium often report experiencing discomforts related to the ocular surface. Notably, these reported symptoms frequently parallel those commonly associated with dry eye disease (DED)[2].

Previous studies have documented a potential association between pterygium and DED. Despite having several pre-established parameters for objectively evaluating dry eye symptoms, understanding the complex relationship between pterygium, the ocular surface, and tear film function remains challenging. Some researchers argue that tear film dysfunction precedes pterygium development and acts as a predisposing factor[3–5]. Conversely, other hypotheses suggest that the compromised ocular surface associated with pterygium contributes to dry eye symptoms by disrupting tear film function[6]. Nevertheless, accumulating research and clinical evidence indicate a relationship between pterygium and DED.

Despite numerous previous reports, the investigation into the features of pterygium associated with clinical characteristics of dry eye remains insufficient, particularly in terms of the morphological alterations of pterygium. The recent adoption of anterior segment swept-source optical coherence tomography (AS SS-OCT) has revolutionized the measurement of anterior corneal elevation parameters in abnormal eyes[7]. This advancement may also greatly improve the assessment of pterygium, offering a more comprehensive understanding of its morphological features.

We hypothesized that geographic alteration of the ocular surface induced by pterygium may be linked to abnormal tear distribution and friction. Therefore, precise identification of morphological features of pterygium can contribute to a more comprehensive understanding of the relationship between pterygium and dry eye parameters, which has not yet been elucidated well. In this study, we aimed to determine whether various morphological profiles of pterygium based on AS SS-OCT are associated with the alteration of the clinical parameters of DED.

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Variables	Value
Age (yrs)	57.6 ± 12.4
% Female (M: F)	48.6% (56:53)
Clinical severity grades	
T grade	
T1	26 eyes (21.3%)
T2	80 eyes (65.6%)
T3	16 eyes (13.1%)
V grade	
V1	18 eyes (14.8%)
V2	81 eyes (66.4%)
V3	23 eyes (18.9%)
Extent of LPS (%)	59.1 ± 29.5

Table 1. Demographics and baseline clinical severities of primary nasal pterygium. Data shows mean ± standard deviation. LPS, loss of vertical length of plica semilunaris.

Morphological profiles	Value
HIL (mm)	3.98 ± 1.24
Height (μm)	986.8 ± 125.0
Thickness (μm)	388.7 ± 115.4
RCT/CCT ratio	1.12 ± 0.15

Table 2. Baseline morphological profiles of primary nasal pterygium based on anterior segment swept-source optical coherence tomography. Data shows mean ± standard deviation. HIL, horizontal invasion length; RCT, residual corneal thickness; CCT, central corneal thickness.

Variables	Value
MG expressibility (Gr)	1.1 ± 0.7
Meibum quality (Gr)	1.0 ± 0.7
Tear osmolarity (mOsm/L)	313.0 ± 28.3
Tear MMP-9 (Gr)	1.4 ± 0.9
Schirmer I without anesthesia (mm)	13.4 ± 8.5
Corneal erosions (NEI scale)	1.6 ± 2.1
SICCA OSS (pterygium)	0.4 ± 0.7

Table 3. Baseline dry eye parameters in subjects with primary nasal pterygium. Data shows mean ± standard deviation. MG, meibomian gland; MMP-9, matrix metalloproteinase 9; Gr, grade; NEI, national eye institute; SICCA OSS, Sjogren's International Collaborative Clinical Alliance ocular staining score.

Results

Demographics and baseline data of morphological profiles of pterygium and dry eye parameters

A total of 122 eyes from 109 patients with primary nasal pterygium were included in this study. Demographic information and baseline clinical severities of pterygium are presented in Table 1. Among the 109 patients, 56 (51.4%) were male, and 53 (48.6%) were female. The average age of all subjects was 57.6 ± 12.4 years (mean ± standard deviation).

Regarding the clinical assessment of the pterygium's severity, 26 eyes (21.3%) were classified as T1, 80 eyes (65.6%) as T2, and 16 eyes (13.1%) as T3. According to the V grades, 18 eyes (14.8%) were categorized as V1, 81 eyes (66.4%) as V2, and 23 eyes (18.9%) as V3. The mean extent of LPS was 59.1 ± 29.5%. The baseline values for horizontal invasion length (HIL), height, thickness, and residual corneal thickness (RCT)-to-central corneal thickness (CCT) ratio (RCT/CCT ratio) of pterygium were 3.98 ± 1.24 mm, 986.8 ± 125.0 μm, 388.7 ± 115.4 μm, and 1.12 ± 0.15, respectively (Table 2).

In this cohort, the baseline dry eye parameters, including MG expressibility grade (1.1 ± 0.7), meibum quality grade (1.0 ± 0.7), tear osmolarity (313.0 ± 28.3 mOsm/L), tear matrix metalloproteinase 9 (MMP-9) grade (1.4 ± 0.9), Schirmer I without anesthesia (13.4 ± 8.5 mm), corneal erosions (National Eye Institute [NEI] scale, 1.6 ± 2.1), and Sjogren's International Collaborative Clinical Alliance ocular staining score (SICCA OSS) on the area of pterygium (0.4 ± 0.7) were recorded (Table 3).

Morphological profiles vs.		MG expressibility (Gr)[a]	Meibum quality (Gr)[a]	Tear osmolarity (mOsm/L)[b]	Tear MMP-9 (Gr)[b]	Schirmer I (mm)[a]	Corneal erosions (NEI scale)[b]	SICCA OSS (pterygium)[b]
HIL	*r*	− 0.060	0.016	− 0.022	0.019	− 0.121	− 0.246	− 0.466
	P value	0.532	0.866	0.815	0.843	0.193	**0.006**	< **0.001**
Height	*r*	− 0.023	− 0.061	0.251	0.053	0.208	0.145	0.262
	P value	0.811	0.524	**0.006**	0.577	**0.024**	0.112	**0.004**
Thickness	*r*	− 0.036	0.019	0.264	0.085	0.278	0.034	0.179
	P value	0.708	0.843	**0.004**	0.375	**0.002**	0.713	**0.048**
RCT/CCT ratio	*r*	− 0.058	− 0.068	− 0.058	− 0.035	− 0.120	0.171	0.131
	P value	0.544	0.480	0.536	0.713	0.197	0.059	0.151

Table 4. Correlation between morphological profiles of pterygium with dry eye parameters in subjects with primary nasal pterygium. [a]Partial correlation test whilst controlling age; [b]Spearman's rank correlation test. MG, meibomian gland; Gr, grade; MMP, matrix metalloproteinase; NEI, national eye institute; SICCA OSS, Sjögren's International Collaborative Clinical Alliance ocular staining score; HIL, horizontal invasion length; RCT, residual corneal thickness; CCT, central corneal thickness. Significant values are in bold.

Correlation vs.[a]		Height	Thickness	RCT/CCT ratio
HIL	*r*	− 0.480	− 0.178	− 0.480
	P value	< **0.001**	0.050	< **0.001**

Table 5. Correlation of horizontal invasion length with other morphological profiles of pterygium including height, thickness and residual corneal thickness-to-central corneal thickness ratio in primary nasal pterygium. HIL, horizontal invasion length; RCT, residual corneal thickness; CCT, central corneal thickness. [a]Spearman's rank correlation test. Significant values are in bold.

Correlation vs.[a]		ACA	RMS LoA	RMS HoA
HIL	*r*	0.772	0.829	0.853
	P value	< **0.001**	< **0.001**	< **0.001**

Table 6. Correlation of horizontal invasion length with anterior corneal astigmatism and root mean square values of corneal aberrations in primary nasal pterygium. HIL, horizontal invasion length; ACA, anterior corneal astigmatism; RMS, root mean square; LoA, lower-order aberration; HoA, higher-order aberration. [a]Spearman's rank correlation test. Significant values are in bold.

Association of the morphological profiles of pterygium with dry eye parameters

Spearman's rank correlation and partial correlation analyses were performed to explore the relationship between the morphological profiles of pterygium and dry eye parameters, as outlined in Table 4. Age was adjusted in the correlation analyses to evaluate MGD grades and tear secretion. A negative correlation was found between HIL and both corneal erosions ($r = -0.246$, $P = 0.006$) and SICCA OSS ($r = -0.466$, $P < 0.001$). In contrast, pterygium height and thickness showed positive correlations with tear osmolarity ($r = 0.251$, $P = 0.006$; $r = 0.264$, $P = 0.004$, respectively), Schirmer I ($r = 0.208$, $P = 0.024$; $r = 0.278$, $P = 0.002$, respectively), and SICCA OSS on the area of pterygium ($r = 0.262$, $P = 0.004$; $r = 0.179$, $P = 0.048$, respectively).

Interestingly, HIL was significantly and negatively correlated with both pterygium height ($r = -0.480$, $P < 0.001$) and the RCT-to-CCT ratio ($r = -0.480$, $P < 0.001$). A marginally significant negative correlation was also observed between HIL and pterygium thickness ($r = -0.178$, $P = 0.050$) in this cohort (Table 5).

To sum up, these findings suggest that a shorter HIL might be associated with increased pterygium height and thickness, potentially leading to greater desiccation, pterygium surface erosions, and increased reflex lacrimation.

Association of corneal astigmatism and aberrations with dry eye parameters

Regarding anterior corneal astigmatism (ACA) and corneal aberration based on AS SS-OCT, HIL showed a significant positive correlation with ACA ($r = 0.772$, $P < 0.001$), the root mean square (RMS) value of corneal lower-order aberrations (LoA) ($r = 0.829$, $P < 0.001$), and the RMS value of higher-order aberrations (HoA) ($r = 0.853$, $P < 0.001$) (Table 6). Reflecting the close correlation between HIL and corneal astigmatism and aberrations, all of ACA, RMS LoA, RMS HoA values were negatively correlated with corneal erosions ($r =$

−0.215, $P = 0.018$; $r = -0.232$, $P = 0.043$; $r = -0.253$, $P = 0.026$, respectively), and SICCA OSS on the area of pterygium ($r = -0.402$, $P<0.001$; $r = -0.407$, $P < 0.001$; $r = -0.426$, $P<0.001$, respectively) (Table 7).

Discussions

Pterygium can cause subjective sensations of discomfort, corneal irregularities, and aesthetic issues. Specifically, it may induce a range of discomforts in affected individuals, including irritation, redness, and a foreign body sensation, all related to ocular surface problems. These complications can impair patients' visual acuity and significantly diminish their quality of life[8]. During clinical assessments, individuals in the early stages of the condition often present with symptoms resembling DED, such as sensations of dryness and irritation. These symptoms may originate from or be aggravated by ocular irritation caused by the elevation of the fibrovascular mass. In this regard, the study aimed to investigate the potential correlation between different morphological profiles of early-stage pterygium, abnormal corneal optical indices, and various clinical parameters of dry eye. The findings highlighted that even in its early stages, pterygium may contribute to desiccation, pterygium surface erosions, and increased reflex lacrimation.

Previous findings have revealed a close relationship between pterygium and ocular surface parameters, as pterygium can contribute to the development of dry eye symptoms due to its potential to induce ocular surface instability[9–13]. However, the causal relationship between tear dysfunction and pterygium growth remains unclear, with ongoing uncertainty about whether tear dysfunction precedes pterygium development or vice versa. Nonetheless, accumulating research and clinical evidence suggests an association between these two phenomena. Eyes affected by pterygium have previously exhibited elevated tear osmolarity levels, increased corneal staining, and heightened conjunctival redness scores compared to the unaffected fellow eyes serving as controls[3]. Despite this established association, there has been a lack of detailed data examining the morphological characteristics of pterygium and their relationship with clinical parameters of dry eye. Given that the shape, length, height, and thickness of pterygium vary significantly among patients, analyzing the relationship between these morphological factors and dry eye parameters is crucial for understanding the specific mechanisms through which pterygium induces ocular surface issues related to dry eye. By identifying specific morphological features linked to dry eye symptoms and signs, our study provides a deeper understanding of how pterygium influences ocular surface stability. This comprehensive analysis also offers valuable insights into determining when abnormal pterygium morphology warrants surgical intervention to improve dry eye-related signs.

To accurately characterize the morphological profiles of pterygium, precise evaluation of its morphology and geography is essential. Previous analyses using placido topography have yielded suboptimal measurements due to incomplete mappings caused by the highly irregular nature of pterygium surfaces[14,15]. In contrast, AS OCT enables more precise quantification of anterior stromal scarring depth at both the pterygium apex and the limbus[16]. Moreover, the integration of AS OCT with swept light source has particularly enhanced pterygium assessment by enabling accurate quantification of anterior corneal elevation parameters with higher resolution in eyes with abnormalities. This has led to a more comprehensive understanding of its morphological characteristics, such as HIL, height, thickness, and the RCT-to-CCT ratio used as profiles in this study. As demonstrated in our recent research, we devised AS SS-OCT-guided morphological and structural indices of pterygium and have proven that they are highly valuable in determining the optimal timing for pterygium surgery[17].

In clinical settings, individuals diagnosed with pterygium frequently present with complaints of discomfort related to the ocular surface. Our findings are consistent with previous research, demonstrating that eyes with pterygium exhibit elevated tear osmolarity. The mean tear osmolarity for all subjects in our study was 313.0 ± 28.3 mOsm/L as shown in Table 3, exceeding the previously recommended abnormal threshold of 308 mOsm/L.[18] Essentially, pterygium initially protrudes, causing irritation. As revealed in Table 4, greater height and increased thickness of the pterygium were associated with higher tear osmolarity, suggesting that abnormal tear distribution induced by pterygium might lead to desiccation and increased osmolarity. It is known that an increase in tear osmolarity may trigger a cascade of alterations in cell architecture and inflammatory changes, potentially resulting in damage to the epithelial surface of the cornea and conjunctiva[19,20]. However, no significant correlation between the height or thickness of the pterygium and tear osmolarity was identified

Astigmatism and aberrations vs.		MG expressibility (Gr)[a]	Meibum quality (Gr)[a]	Tear osmolarity (mOsm/L)[b]	Tear MMP-9 (Gr)[b]	Schirmer I (mm)[a]	Corneal erosions (NEI scale)[b]	SICCA OSS (pterygium)[b]
ACA	*r*	− 0.066	− 0.035	− 0.048	− 0.074	− 0.118	− 0.215	− 0.402
	P value	0.493	0.713	0.610	0.436	0.323	**0.018**	< **0.001**
RMS LoA	*r*	− 0.110	− 0.042	− 0.129	− 0.058	− 0.098	− 0.232	− 0.407
	P value	0.373	0.738	0.282	0.634	0.414	**0.043**	< **0.001**
RMS HoA	*r*	− 0.057	− 0.068	− 0.050	− 0.022	− 0.150	− 0.253	− 0.426
	P value	0.646	0.584	0.680	0.857	0.210	**0.026**	< **0.001**

Table 7. Correlation analysis of anterior corneal astigmatism and root mean square values of corneal aberrations with dry eye parameters in subjects with primary nasal pterygium. MG, meibomian gland; Gr, grade; MMP, matrix metalloproteinase; NEI, national eye institute; SICCA OSS, Sjögren's International Collaborative Clinical Alliance ocular staining score; HIL, horizontal invasion length; RCT, residual corneal thickness; CCT, central corneal thickness. [a]Partial correlation test whilst controlling age; [b]Spearman's rank correlation test. Significant values are in bold.

in earlier studies. Additionally, given that tear MMP-9 and corneal erosions were not correlated with pterygium height and thickness, we believe that the increased tear osmolarity observed in taller and thicker pterygium may not be sufficient to cause DED. In this context, we hypothesize that the increased Schirmer I results observed in taller and thicker pterygium might be due to reflex tearing, alongside the increased SICCA OSS on the area of pterygium, which was also considered a friction-related phenomenon. Additionally, in our cohort subjects, as HIL lengthened, the height and thickness of the pterygium decreased, which we believe contributed to a reduction in abnormal tear distribution and friction in more advanced pterygium cases paradoxically.

Previous research has demonstrated a significant correlation between pterygium size and both corneal astigmatism and ocular wavefront aberrations[15,21,22]. Specifically, pterygia are known for their tendency to increase levels of astigmatism and higher-order aberrations as they grow in length and extend onto the cornea[22–25]. This study further elucidated that greater pterygium length is inversely associated with corneal and conjunctival erosion, contrasting with the previously recognized optically detrimental effects of longer pterygia. To summarize the opposing effects of pterygium invasion on optical quality and dry eye parameters, both early-stage and advanced pterygium have unique influences on patients with pterygium.

In statistical analysis of this study, a partial correlation analysis was conducted to investigate the relationship between the variables of interest while adjusting for the potential confounding influence of age, given its significance for both pterygium and MGD or DED occurrence[26]. Previous research has shown that the prevalence of pterygium may increase with age[27], while prior studies demonstrate that Schirmer I test values and tear film stability decrease with age[28–31], coinciding with the increased prevalence of DED with advancing age[22]. Future research efforts can also include comprehensive histopathologic studies to thoroughly elucidate the relationship and underlying mechanisms between pterygium and DED.

Due to the retrospective nature of the study, it is possible that patients' medical histories and comorbidities were not fully controlled. Additionally, we did not limit the subjects with DED-diagnosed patients but enrolled patients who were evaluated for dry eye. While this study acknowledges certain limitations and underscores the necessity for further investigation, it is essential to note that exploring the relationship between pterygium and dry eye poses challenges due to potential differences in genetic backgrounds and exposure to environmental factors among affected patients. Moreover, this is the first study to evaluate objective preoperative morphological profiles of pterygium based on AS SS-OCT that correlate with clinical indicators of dry eye-related parameters.

In conclusion, HIL inversely correlates with pterygium height and thickness, and early-stage pterygium is considered to induce desiccation, surface erosions, and increased reflex lacrimation. Although more advanced pterygium, characterized by longer HIL, increases corneal astigmatism and aberration, it may be associated with less severe dry eye-related parameters. This novel finding offers clinicians valuable insights into the mechanisms of pterygium progression, enabling a more comprehensive understanding for patient care.

Methods

This investigation, conducted at a single center, constituted a retrospective cohort study based on medical chart review. Adherence to the principles in the Declaration of Helsinki was ensured throughout the entire investigation process. Approval for the research protocol was obtained from the Institutional Review Board (IRB) of Chung-Ang University Hospital (Approval No. 2307-001-19478). Given the retrospective nature of the study, the need for informed consent was waived by the IRB of Chung-Ang University Hospital.

Subjects

This study included individuals diagnosed with nasal-only primary pterygium who underwent preoperative assessment using AS SS-OCT (Anterion®, Heidelberg, Germany) and dry eye evaluations from September 2021 to June 2023. All participants underwent a comprehensive ophthalmological examination following a standardized protocol. We excluded subjects who had a systemic immunologic disease, including Sjogren's syndrome and allergic disease. We also excluded those who were under systemic immune-related treatments or were using topical administration of anti-inflammatory eye drops or anti-glaucomatous eye drops. Furthermore, participants who had worn contact lenses within the previous three months were excluded, as were those who had undergone ocular surgery within the previous six months.

Study design

The design of our study was outlined as follows:

1. Collection of baseline pterygial morphological profiles, including HIL, pterygium height and thickness, and the RCT-to-CCT ratio, as well as corneal optical properties, including ACA, RMS LoA, and RMS HoA, based on AS SS-OCT before surgery.
2. Collection of the clinical parameters of dry eye including MG expressibility grade, meibum quality grade, tear osmolarity, tear MMP-9 grade, Schirmer I without anesthesia, corneal erosions (NEI scale), and SICCA OSS on the area of pterygium.
3. Correlation analysis of morphological profiles and corneal optical properties of pterygium with dry eye parameters.

Estimation of the morphological profiles of pterygium and corneal optical properties based on AS SS-OCT

The morphological profiles of pterygium based on AS SS-OCT which were undergone less than 4 weeks before surgery was estimated. As morphological profiles of pterygium, we devised four parameters including HIL (mm), height (μm), thickness (μm), and the ratio of RCT-to-CCT (i.e. RCT/CCT ratio). Additionally, corneal optical properties, such as ACA, RMS LoA, and RMS HoA, were evaluated.

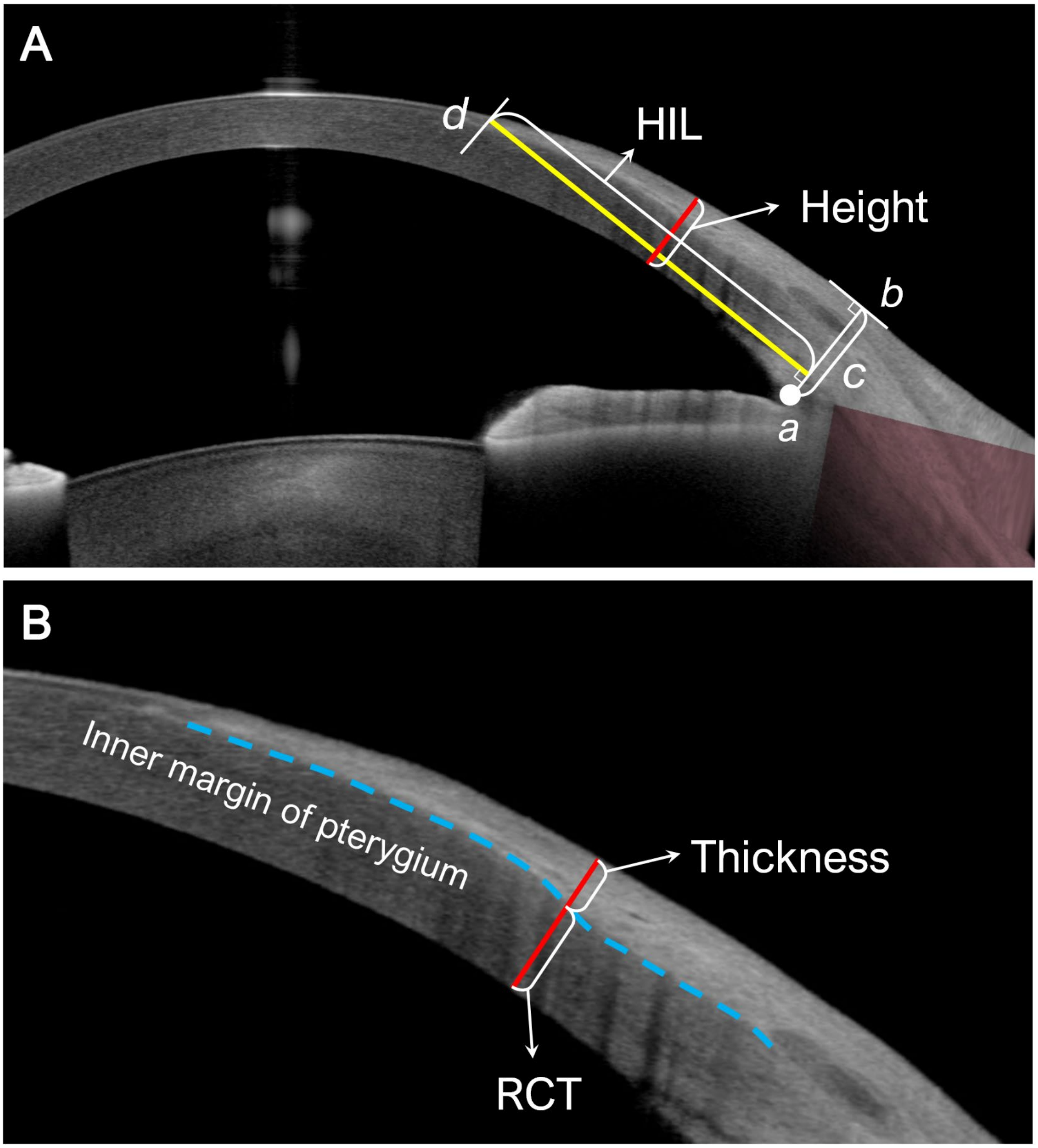

Fig. 1. Pterygial morphological profiles in anterior segment swept-source optical coherence tomography. (**A**) Photograph representing the definition of horizontal invasion length (HIL) and height of pterygium. HIL is defined as a linear distance from the vertical line (c) connecting a scleral spur (a) to a point (b) vertically extended on a surface tangent line to the end of the pterygium head (d). Pterygial height is defined as the vertical distance between the corneal endothelium and the outermost pterygium surface measured at the midpoint of the HIL. (**B**) The magnified photograph of A to define the residual corneal thickness (RCT) and pterygial thickness. Pterygial thickness is defined as the length from the inner margin of the pterygium to the outer surface within the height of the pterygium at the midpoint of the HIL. RCT is defined as the distance from the corneal endothelium to the inner margin of the pterygium within the height of the pterygium at the midpoint of the HIL.

The methodology of AS SS-OCT-guided morphological profiling of pterygium has been established recently[17]. The AS SS-OCT imaging was performed while the subject maintained a forward gaze, with the equipment automatically tracking the eye during the capture. Due to the auto-tracking capability of the device, imaging was conducted only once per subject. Parameters were assessed using images provided by the metrics app within Anterion® AS SS-OCT, as shown in Fig. 1. The HIL was defined as the linear distance from the vertical line (c) connecting the scleral spur (a) to a point (b) vertically extended on a surface tangent line to the end of the pterygium head (d) (Fig. 1A). Pterygium height was defined as the vertical distance between the corneal endothelium and the outermost pterygium surface, measured at the midpoint of the HIL (Fig. 1A). Pterygial thickness was defined as the distance from the inner margin of the pterygium to its outer surface within the pterygium's height at the midpoint of the HIL (Fig. 1B). RCT was defined as the distance from the corneal endothelium to the inner margin of the pterygium within the height of the pterygium at the midpoint of the HIL

(Fig. 1B). CCT value was obtained using the metrics app. ACA values were measured from a 3 mm ring using the cornea app. Regarding RMS LoA and RMS HoA, values within a 6 mm diameter zone were acquired from the cornea app.

Clinical severity grading of pterygium

All eyes affected by pterygia underwent assessment using three predefined severity grading systems, which evaluated various aspects including the translucency and vascularity of the pterygium body stroma, denoted as T grades[32] and V grades[33], respectively, as well as the degree of morphological alteration in the vertical length of the plica semilunaris (LPS)[34]. Standard photographs were utilized to aid in the application of all three grading systems. These clinical grading systems for pterygium are considered highly reliable as it is based on standard photographs or a clear estimation methodology[35], and they were significantly correlated with the AS SS-OCT-guided morphological indices of pterygium used in this study. Therefore, a single examiner performed the assessment of pterygium in all subjects.

Briefly, the T grading system categorized pterygia into T1, T2, and T3, representing differing levels of translucency, ranging from clear visibility to complete coverage of underlying episcleral vessels by the pterygium body. Similarly, the V grading system classified pterygia into V1, V2, and V3 based on the degree of vascularity, ranging from minimal to marked vascularization. The assessment of LPS was carried out using digital photographs (magnification ×10) captured by a slit lamp imaging system during lateral gaze, both with and without a yellow barrier filter. The extent of LPS was quantified as the ratio of its length within the plica semilunaris to the total length of the plica semilunaris, expressed as a percentage (%), following a previously established methodology[34].

Dry eye parameters

In our evaluation of parameters related to dry eye, we assessed the clinical grades of MG expressibility and quality of secreted meibum, tear osmolarity, tear MMP-9 grades, tear secretion via Schirmer I test without anesthesia, corneal erosions (NEI scale), and SICCA OSS. All clinical parameters for dry eye were consistently evaluated by a single researcher (K.W.K).

MG expressibility was determined by assessing the outflow of meibum from five central upper eyelid glands upon finger squeezing. Grades range from 0 to 3: Grade 0 indicates all glands are expressible, grade 1 signifies expressibility of 3–4 glands, grade 2 denotes expressibility of 1–2 glands, and grade 3 indicates no expressible glands. Meibum quality, evaluating turbidity, is graded from 0 to 3: grade 0 for clear fluid, grade 1 for cloudy, grade 2 for cloudy and particulate, and grade 3 for opaque, toothpaste-like fluid. MG expressibility and meibum quality were evaluated based on established criteria[20].

Tear osmolarity was determined by sampling from the inferior lateral tear meniscus of eyes with pterygium, utilizing a disposable microchip to facilitate tear fluid collection via passive capillary action. Subsequent to tear fluid collection, the microchip was inserted into an I-PEN® (I-MED Pharma Inc., Montreal, QC, Canada), which showed the test results in digits.

The tear MMP-9 test was conducted using point-of-care test (InflammaDry®, Quidel, USA) in accordance with the manufacturer's instructions provided in the product documentation. A sterile sample collector was utilized to collect tear fluid from various points along the lower palpebral conjunctiva, which was subsequently assembled into the immunoassay test cassette. Following a 20-second activation period in buffer solution, the intensity of the red line in a readout window was examined for verification. The tear MMP-9 grade was assessed using a pre-established 5-point grading system ranging from 0 to 4, which demonstrated excellent reliability and validity, accurately reflecting the actual concentration gradient of MMP-9 in tears[36].

Schirmer I test was conducted without topical anesthesia, using a standardized filter strip (EagleVision, Memphis, TN, USA) on the outer 1/3 point of the lower conjunctival fornix to assess tear secretion subsequent to a 5-minute interval.

Additionally, the ocular staining score was assessed according to established standards by individually examining each eye with a slit-lamp under a yellow filter following fluorescein instillation[37]. The SICCA score[38] and corneal erosions according NEI scale[39] were acquired in accordance with established criteria and protocols. For SICCA scoring in particular, the area assessed was confined to the pterygium body to evaluate its influence on the conjunctival staining score.

Statistical analysis

Statistical analyses were performed using Prism software (GraphPad, La Jolla, CA, USA) and SPSS software (Chicago, IL, USA). The correlation test was performed using non-parametric Spearman's rank correlation test. In addition, partial correlation test whilst controlling age was performed. We conducted a partial correlation analysis to investigate the relationship between the variables of interest while accounting for the potential confounding influence of age, with the aim of improving the validity of the study's findings. The data are presented as mean ± standard deviation (SD), and statistical significance was set at a P value < 0.05.

Data availability

The datasets generated and analyzed in the current study are available from the corresponding author on reasonable request.

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K.W.K designed the study. H.D.H collected data. K.W.K analyzed the data. H.D.H wrote the manuscript. K.W.K. revised the manuscript.

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Declarations

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