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ORIGINAL ARTICLE

Tear Meniscus Analysis with Fourier-Domain Optical Coherence Tomography in Keratoconus

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ABSTRACT

Purpose: To measure the lower tear meniscus dynamics with Fourier domain-optical coherence tomography (FD-OCT) in keratoconus patients without dry eye findings to evaluate the effects of the corneal ectasia on lower tear meniscus parameters, and to determine the most affected meniscus variable from the corneal ectasia in keratoconus.

Methods: Prospective, clinical study. Forty-one eyes of 25 keratoconus patients without dry eye and 40 eyes of 20 healthy subjects were included. The lower tear meniscus analysis with FD-OCT, and corneal topography, keratometry, and pachymetry measurements were performed in all eyes. The main outcomes, including the lower tear meniscus height (TMH), depth (TMD), area (TMA), and angle between cornea and the tear meniscus (α-angle), were assessed. The results were compared between the patients and the control subjects.

Results: The average keratometric power was 53.94 ± 5.76 D (between 44.46 to 63.75 D) in keratoconic eyes. It was 43 ± 0.8 D (between 40.50 to 45.94 D) in the controls. The average TMH, TMD, and TMA values did not show any statistically significant difference between the patients and the controls ($p = 0.39$, $p = 0.824$, $p = 0.516$, respectively). However, the average value of the α-angle was significantly higher in keratoconic eyes when compared to controls ($p = 0.031$). It was positively correlated with the keratometric power ($r = 0.577$, $p = 0.001$).

Conclusions: The TMH, TMD, and TMA did not show any change with the corneal protrusion; however, the α-angle had positive correlation with the keratometric power in keratoconic eyes.

Keywords: α-angle, Keratoconus, Fourier domain-optical coherence tomography, Tear meniscus area, Tear meniscus depth, Tear meniscus height

INTRODUCTION

Keratoconus is a bilateral and asymmetric ectatic corneal dystrophy characterized by corneal thinning, anterior protrusion, and irregular astigmatism.[1–3] The etiology of this progressive disease is still unknown and most likely thought to be genetic and multifactorial.[3] Advanced keratoconus is easy to demonstrate by the characteristic clinical findings, such as scissors reflex during retinoscopy, corneal thinning, Fleischer's ring, Vogt's striae, Munson's sign, Rizzutti's sign, or increased visibility of the corneal nerves and the keratometry readings.[3] However, the diagnosis of early keratoconus is challenging and generally needs the assistance of advanced technology.[3,4] Currently, computerized corneal topography is the most sensitive diagnostic tool that detects early keratoconus before the development of the classic symptoms.[5,6]

In recent years, application of optical coherence tomography (OCT) to evaluate the anterior structures of the eye, such as cornea, limbus, and tear film has achieved increasing popularity.[7–13] In numerous studies, tear meniscus dynamics have been imaged by OCT for the diagnosis of dry eye.[9–13] It has been reported that, with its high depth resolution, OCT can evaluate the tear meniscus more precisely than the conventional methods.[9–13] However, in some ocular conditions, such as conjunctivochalasis and disorders of lid margin congruity that can cause lid apposition on the ocular surface, OCT is not expected to be a useful and reliable tool for evaluating tear meniscus.[13]

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In the present study, we mainly aimed to evaluate the effects of the corneal shape on the tear meniscus dynamics analyzed with OCT. For this purpose, we used Fourier domain (FD)-OCT to image the lower tear meniscus in keratoconus patients. We recruited keratoconus patients who did not have any dry eye findings to eliminate the effects of dry eye on the lower tear meniscus variables. We hypothesized that the variables of the lower tear meniscus such as height (TMH), depth (TMD), area (TMA), and angle (α-angle) may change due to the protrusion of the cornea in keratoconic eyes. Secondly, we aimed to determine the most affected meniscus variable from the corneal protrusion. To our knowledge, the evaluation of lower tear meniscus with OCT in keratoconic eyes has never been previously reported.

METHODS AND MATERIALS

Forty-one eyes of 25 keratoconus patients without dry eye (15 women, 10 men; mean age, 26.93 ± 5.1 years) and 40 eyes of 20 healthy subjects (12 women, 8 men; mean age, 29.52 ± 7.15 years) were recruited from the Department of Ophthalmology of Ataturk Training and Research Hospital from January 2010 through September 2010 in this prospective study. The study was conducted in compliance with the institutional and government review board regulations, informed consent regulations, and the Declaration of Helsinki. Written informed consent was obtained from all patients and the control subjects before the clinical evaluation.

Patients who had dry eye, any corneal scar, any other ophthalmic or systemic disorder, undergone any ocular surgery, or used contact lenses within the previous 12 months were excluded from the study. None of the patients had been using any topical ophthalmic medication within the prior 3 months.

The diagnosis of dry eye was made based on the following two criteria: (1) Schirmer tear test (without anesthesia) lower than 10 mm/5 min, and (2) tear breakup time (TBUT) lower than 10 sec. The dry eye diagnosis was made if both criteria were present.[14]

To perform the Schirmer tear test, a standard Schirmer test strip was placed in the lower fornix at the junction of the lateral and middle third, taking care to avoid touching the cornea. After 5 min, the strips were removed and the wetted length of the test strip was measured in millimeters to determine the Schirmer test value.

To measure TBUT, a fluorescein sodium strip moistened with a drop of non-preserved saline solution was applied to the inferior palpebral conjunctiva in each eye. After removing the strip, the patient was asked to blink three times and then look straight forward. The precorneal tear film was examined with a biomicroscope, and the elapsed time before the initial breakup, rupture of the tear film, or formation of tiny dry spots were recorded. The TBUT was measured three times, and the measurements were averaged.

The ophthalmologic examination consisted of visual acuity testing; slit-lamp examination; fundoscopic examination; determination of TBUT; Schirmer test without anesthesia; and topographic, keratometric, and pachymetric examinations of the cornea. Keratoconic eyes were diagnosed clinically; they had at least one clinical sign other than the topographic appearance of the map, which included Munson's sign, scissors reflex during retinoscopy, corneal thinning, Fleischer's ring, Vogt's striae, increased visibility of the corneal nerves, and Rizzutti's sign.[3]

According to the study protocol, 1week after the ophthalmologic examination the lower tear meniscus variables were imaged with OCT.

Imaging Procedure

Before obtaining the images with OCT, the room temperature was set between 20°C and 22°C, and humidity was maintained at 30–50%. The room light was dimmed to avoid reflex tearing. To evaluate the tear meniscus parameters, an FD-OCT system (RTVue, software version 2.7; Optovue Inc., Fremont, California, USA) with a corneal-anterior module (CAM) was used.[12,15] The FD-OCT is a high speed and high resolution OCT, which takes 26,000 A-scans per second, with a frame rate of 256 to 4096 A-scans per frame. It has a depth resolution of 5 μm and a transverse resolution of 15 μm. The scan range is 2–2.3 mm in depth and 2–12 mm in the transverse plane. The scan beam wavelength is 840 ± 10 nm.[15] The cornea-anterior module is an additional software on the device, which helps in anterior segment imaging.

All tests were performed by the same examiner (G.S.). Three images per eye were obtained and the best image showing the lower tear meniscus was used in the analysis. Each participant was instructed to fixate on an external fixation target positioned in the primary position. The measurements were made on the meniscus at the central lower lid of the eye. Before imaging the meniscus the participants were asked to blink, and immediately after blinking the image was taken. The tear meniscus parameters were calculated as described in previous studies.[11,12] The TMH, TMD, TMA, and α-angle were measured from scanned images using customized software. The TMH was measured from the cornea meniscus junction to the lower lid meniscus junction (Figure 1A). The TMD was measured from the midpoint of the air meniscus interface to the cornea lower eyelid junction (Figure 1B). The TMA was calculated by fitting a triangle (Figure 1C). The α-angle was the angle between the lower tear meniscus surface and inferior cornea (Figure 1D).

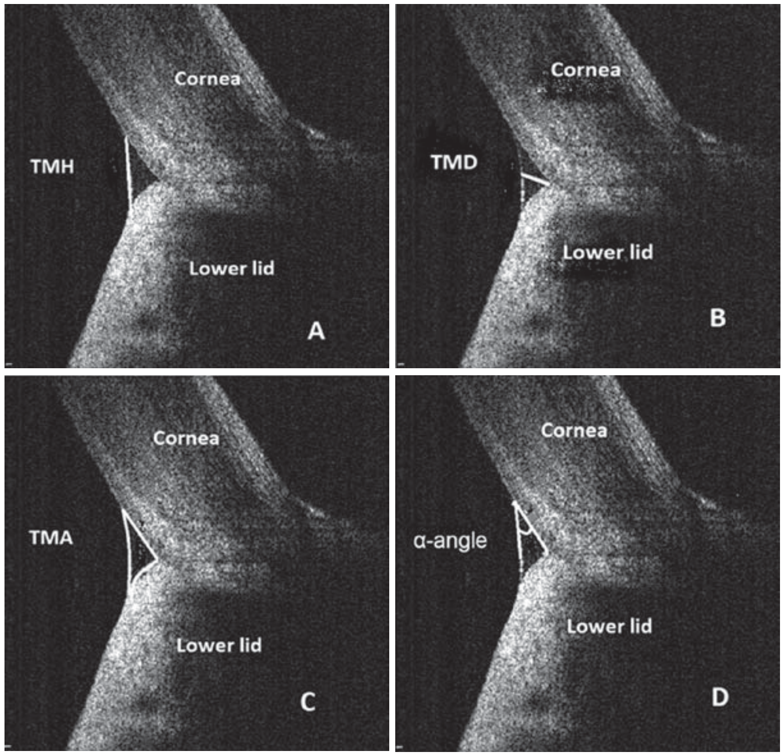

FIGURE 1 Optical coherence tomography (OCT) images of lower tear meniscus variables in a keratoconic eye obtained by Fourier domain (FD)-OCT. The figures show tear meniscus height (TMH) (A), tear meniscus depth (TMD) (B), tear meniscus area (TMA) (C), and angle between the lower tear meniscus surface and the inferior cornea (α-angle) (D). All the images have been cropped and magnified.

Statistical Analysis

Statistical analysis was performed using the Statistical Package for Social Sciences software (version 16.0, SPSS, Inc., Chicago, IL, USA). The significance of difference in the mean TMH, TMD, TMA, and α-angle was assessed by the student *t* test (independence samples test) between patients and controls. The Pearson correlation (*r*) was used to determine the correlations between variables. All data were presented as means ± standard deviations for all patients and controls. Differences were considered statistically significant at $p \leq 0.05$.

RESULTS

There were 15 women (60%) and 10 men (40%) in the patient group. The average patient age was 26.93 ± 5.1 years (between 16–39 years). The control group consisted of 12 women (60%) and 8 men (40%) with an average age of 29.52 ± 7.15 years (between 18–37 years).

Keratoconic eyes had an average keratometric power of 53.94 ± 5.76 D (between 44.46 to 63.75 D). The average spherical refractive error of these eyes was -6.0 ± 8.1 D (between 0 to -10.5 D). The average cylinderic refractive error was -4.1 ± 3.2 D (between -1.5 to -8.5 D). The average central corneal thickness (CCT) was 455 ± 34.77 µm (between 378 to 506 µm). For the control subjects, the average keratometric power was 43 ± 0.8 D (between 40.50 to 45.94D). The average spherical and cylindrical refractive errors were -1.56 ± 4.1 D (between -3.0 to +1.5 D) and 1.2 ± 1.3 D (between -2.5 to +0.5 D), respectively. The average CCT was 541 ± 51.8 µm (between 490 to 580 µm).

The average TMH was 250.77 ± 66.47 µm in the keratoconic eyes. In the controls it was 233.00 ± 76.99 µm, and the difference was not statistically significant ($p = 0.391$, Table 1). The average TMD in the keratoconic eyes was 188.68 ± 46.23 µm, compared with 188.03 ± 57.38 µm in the controls. The difference was not statistically significant ($p = 0.824$, Table 1). The average TMA was 0.0315 ± 0.019 mm^2 in keratoconic eyes vs. 0.0275 ± 0.023 mm^2 in the control subjects. The difference was not statistically significant ($p = 0.516$, Table 1). There was no correlation between the TMH, TMD, and TMA values and the keratometric power ($r = 0.059$, $r = 0.053$, $r = 0.030$, respectively, $p > 0.05$). Also, there was no correlation between the TMH, TMD, and TMA values and the CCT ($r = 0.150$, $r = 0.255$, $r = 0.065$, respectively, $p > 0.05$).

The average value of the α-angle was 35.27° ± 6.77° in the control subjects. It was significantly increased to 42.3° ± 11.25° in the keratoconic eyes ($p = 0.031$, Table 1). As seen in Figure 2, it was positively correlated with the keratometric power ($r = 0.577$, $p = 0.001$). There was no correlation between the α-angle and the CCT ($r = 0.235$, $p > 0.05$).

There was no significant effect of gender on the average value of TMH, TMD, TMA, and the α-angle ($p > 0.05$).

DISCUSSION

Tear meniscus imaging with OCT has been performed in recent years, and validated in numerous studies.[9–13] The repeatability of this method was assessed, and since it is noninvasive and induces little or no reflex tearing, it was previously found to be highly repeatable.[16,17] In the present study, we used FD-OCT to image the lower tear meniscus in keratoconus patients without dry eye to evaluate the effects of the corneal protrusion on the tear meniscus variables.

The cornea is the principal refracting surface of the eye, and has a typical shape of a prolate ellipse, flattening from apex to periphery.[18] In keratoconus, the cornea begins to thin, and bulges forward taking on a cone shape, which is associated with the displacement of the axes of the collagen fibrils and distortion of the orthogonal matrix.[19]

TABLE 1 Lower tear meniscus variables in keratoconic eyes and control subjects.

	Keratoconic eyes	Control subjects	p-Value
TMH, μm	250.77 ± 66.47	233.00 ± 76.99	0.391
TMD, μm	188.68 ± 46.23	188.03 ± 57.38	0.824
TMA, mm^2	0.0315 ± 0.019	0.0275 ± 0.023	0.516
α-Angle	42.3° ± 11.25°	35.27° ± 6.77°	0.031

TMH: lower tear meniscus height; TMD: lower tear meniscus depth; TMA: lower tear meniscus area; α-angle: the angle between the lower tear meniscus surface and the inferior cornea.

Dry eye symptoms are present in 81.5% of keratoconus patients.[20] Seventy percent of keratoconus patients were found to have TBUT-deficient dry eye, and with an increase of tear film instability, keratoconus progressed.[20] There are numerous factors that promote dry eye in keratoconus. The reduction of corneal sensitivity, the release of collagen degradation products into the tears, and the alteration of the surfacing of the tear on the cornea in keratoconus patients are the major causes of dry eye.[20] Squamous metaplasia of the conjunctival and corneal epithelial surfaces along with the decreased goblet cell population demonstrated in these patients are the other participitating factors for dry eye.[20]

OCT has been gaining popularity among clinical researchers in the field of dry eye assessment by evaluating the upper and/or lower tear meniscus.[11–13,15–17] In dry eye patients, it was shown that the tear meniscus height and depth were decreased in comparison to normal subjects.[11,16,17] In this study, we performed FD-OCT, which has recently been introduced to ophthalmic practice, and has much greater speed and sensitivity than conventional OCT. It is 260 times faster than the OCT1 (Carl Zeiss Meditec, Dublin, California, USA), 13 times faster than the Visante-time domain OCT (Carl Zeiss Meditec), and 6.5 times faster than the time-domain OCT.[12] Compared to other OCT systems used for tear meniscus measurement, it has higher depth resolution. Additionally, the effect of eye motion on the measurement is minimal in FD-OCT system.[12,15] For these reasons, the measurement of tear meniscus with FD-OCT

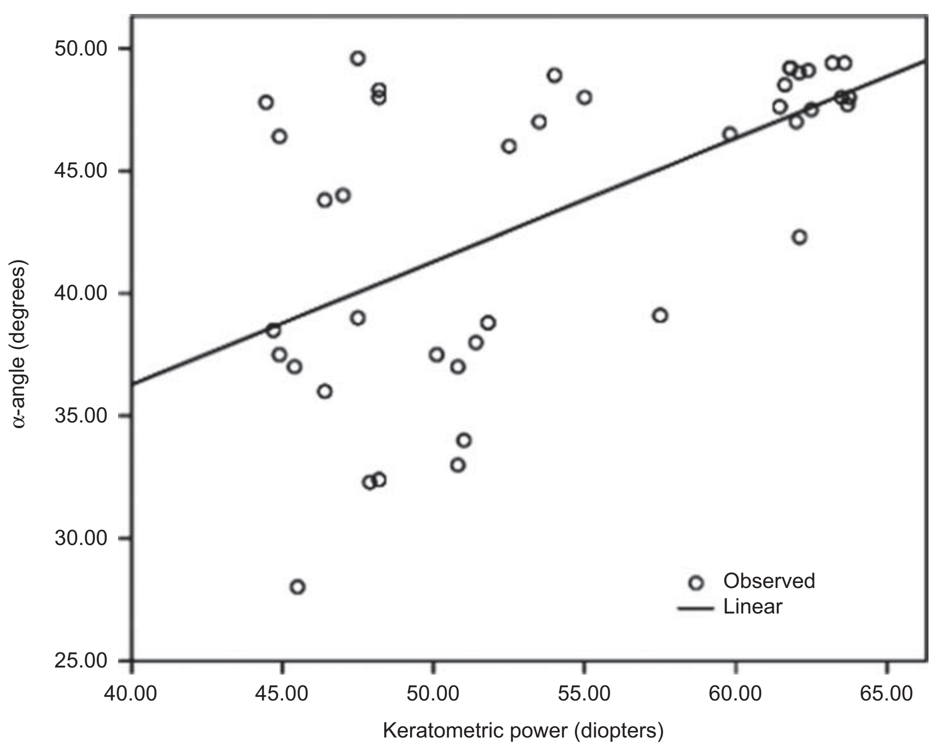

FIGURE 2 Scatter plot demonstrating the positive correlation between the α-angle (angle between the lower tear meniscus surface and the inferior cornea) and the keratometric power in keratoconic eyes ($n = 41$ eyes), ($r = 0.577$, $p = 0.001$).

should be more accurate compared to the commercial OCT systems.

Our study group consisted of patients with mild to advanced keratoconus without dry eye. The average TMH, TMD, and TMA values did not show any statistically significant differences between the patients and the controls. These values were not correlated with the degree of corneal steepening and CCT. Interestingly, the average α-angle was significantly high and positively correlated with the keratometric power of the cornea in keratoconic eyes (Figure 3) when compared to controls. The α-angle is a measure of corneal surface wetability and demonstrates the distribution of the tear film on the corneal surface. Zhou et al. showed the α-angle to have a small variance in normal eyes.[12] Currently, there is no data on the clinical significance of this valuable parameter. We consider that the increase of the α-angle in our study group might have resulted primarily from the corneal ectasia causing an alteration in the relationship of the ocular surface and the eyelids.

There are some limitations in the present study. First, the keratoconus patients were not grouped according to the severity of the keratoconus. Second, the type and location of the conus in keratoconic eyes were not taken into account while analyzing the tear meniscus variables. Despite these limitations, we believe that this study provided information about the effects of the corneal protrusion on lower tear meniscus variables imaged with OCT.

CONCLUSION

This study quantified lower tear meniscus parameters of keratoconic eyes for the first time using FD-OCT.

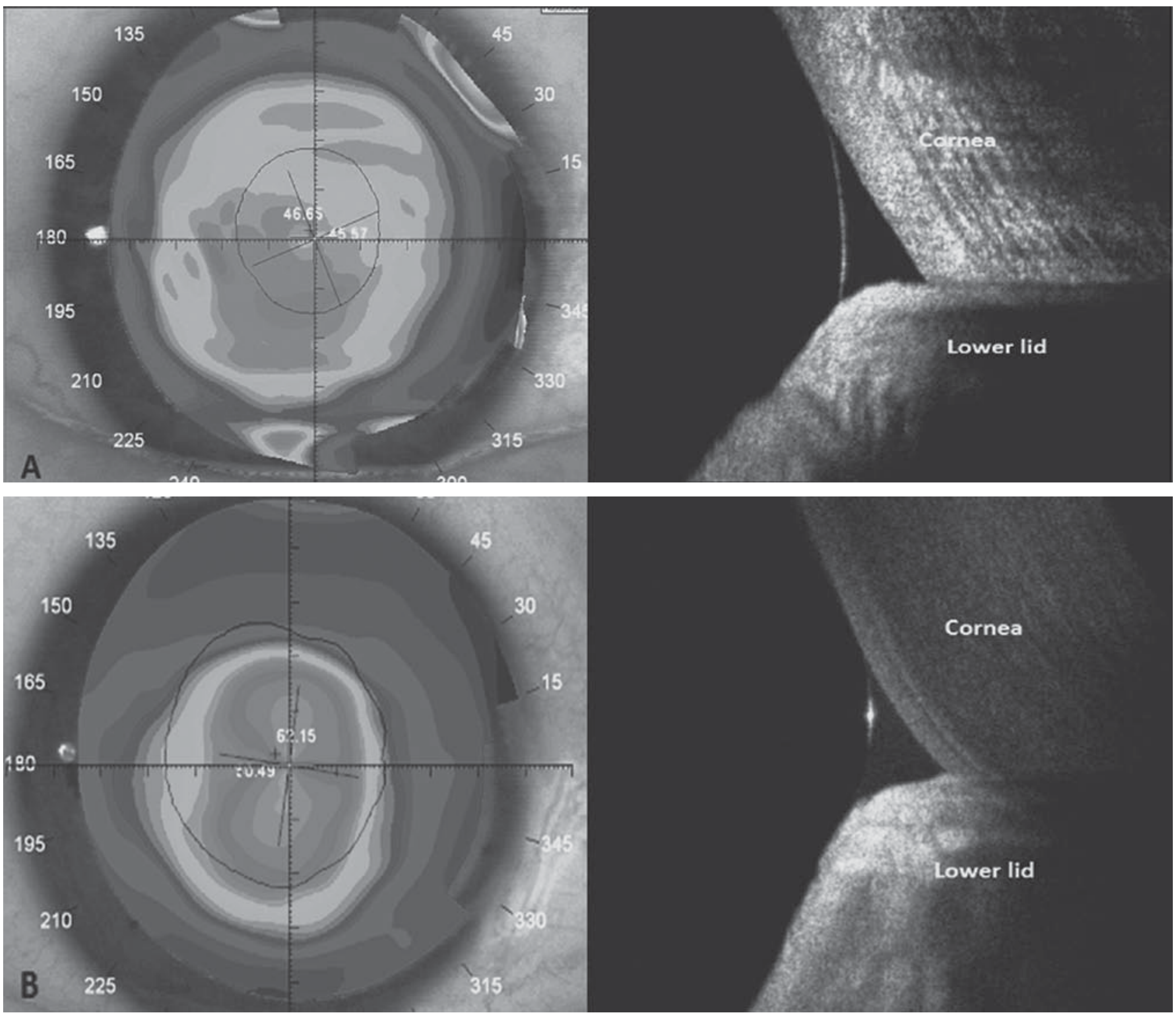

FIGURE 3 Corneal topographic and Fourier domain-optical coherence tomography (FD-OCT) images of lower tear meniscus of a moderate (A) and an advanced (B) keratoconic eye. The moderate keratoconic eye had a lower degree of tear meniscus angle (α-angle) when compared to the advanced keratoconic eye.

The findings of our study demonstrated that corneal protrusion in keratoconic eyes only affected α-angle, the angle between the inferior cornea and the tear meniscus surface. Keratoconic eyes had higher degrees of α-angle than normal eyes, which were positively correlated with the keratometric power.

As the current study consisted of only keratoconus patients without dry eye, further studies with keratoconus patients with dry eye are needed to evaluate the use of α-angle measured with OCT for the diagnosis of dry eye in keratoconus patients. False negative results can be achieved in dry eye patients with keratoconus who have high keratometric powers. On the other hand, we think that α-angle measured with OCT might be used as a diagnostic parameter for keratoconus in the future. Further work is required to assess the accuracy and the repeatability of the measurement of α-angle with OCT in keratoconus patients.

***Declaration of interest*:** The authors report no conflict of interest. The authors alone are responsible for the content and writing of the paper.

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