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Is contact lens discomfort related to meibomian gland morphology?

Marta Blanco-Vázquez [a,1], Cristina Arroyo-Del-Arroyo [a], Andrea Novo-Diez [a], Pilar Cañadas [a], Alberto López-de la Rosa [a,*], María J. González-García [a,b]

[a] Instituto Universitario de Oftalmobiología Aplicada (IOBA), Universidad de Valladolid, Valladolid, Spain
[b] Networking Research Center on Bioengineering, Biomaterials and Nanomedicine (CIBER-BBN), Valladolid, Spain

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ABSTRACT

Purpose: To examine the relationship between contact lens (CL) discomfort and meibomian gland (MG) morphology assessed by a semi-objective software in subjects without an alteration of MG function (meibum quality and expressibility).

Methods: Nineteen symptomatic (CLDEQ-8 $\geq$ 12) CL wearers, 19 asymptomatic (CLDEQ-8 $<$ 12) wearers, and 22 non-wearers were recruited. Upper and lower eyelid meibography images were taken and the following parameters were analysed using a semi-objective software in the central 2/3 of each eyelid: number of MG, number of partial MG, percentage of MG loss and percentage of tortuosity. One-way ANOVA or Kruskal-Wallis H test were used for comparisons among groups. The relationships between CLDEQ-8 and MG morphology parameters were analysed using the Spearman correlation coefficient and multivariable linear regression models.

Results: No significant differences were found among groups in the MG morphology of the upper or lower eyelids. In all CL wearers, a significant correlation with CLDEQ-8 was found in the upper eyelid for the number of MG (rho = 0.47, p = 0.003). In symptomatic wearers, significant correlations with CLDEQ-8 were found in the lower eyelid for the number of partial MG (rho = 0.49, p = 0.03) and the percentage of partial MG (rho = 0.61, p = 0.005). In all CL wearers, multivariable models were fitted to explain CLDEQ-8 score including the number of MG, the number of partial MG and the percentage of MG loss from the lower eyelid (R^2 = 0.19; p = 0.007), and the number of MG from the upper eyelid (R^2 = 0.19; p = 0.001). In symptomatic wearers, a model was fitted including the percentage of MG loss from the lower eyelid (R^2 = 0.30; p = 0.016).

Conclusions: Alterations of MG morphology, without clinically apparent alteration of MG function, can be involved in causing CL discomfort and influence the degree of symptoms. The differences in findings between eyelids indicate the need to monitor both eyelids, especially the lower one, in CL wearers.

1. Introduction

Contact lens (CL) discomfort is a condition suffered by 31–58 % of wearers [1], and is the main reason for permanent discontinuations at a rate that has been variously reported as between 12 % and 51 % [2]. The Tear Film & Ocular Surface Society Workshop on Contact Lens Discomfort defines CL discomfort as "a condition characterized by episodic or persistent adverse ocular sensations related to lens wear, either with or without visual disturbance, resulting from reduced compatibility between the contact lens and the ocular environment, which can lead to decreased wearing time and discontinuation of contact lens wear" [3]. Some of the causes of CL discomfort that have been suggested so far are tear film instability [4,5], increased tear film evaporation [4–7], inflammation [8–10], dewetting of the CL surface [7], lid-wiper epitheliopathy, and alterations of the meibomian glands (MG) [11]. MG alterations and lid-wiper epitheliopathy are the two issues that show the strongest link to CL discomfort [11].

MG are sebaceous glands located in the tarsal plates of the eyelids that synthesize and secrete mainly lipids into the tear film. These lipids from the lipid layer play a fundamental role in the stability of the tear film, reducing the evaporation of the aqueous component, preserving a clear optical surface, and forming a barrier to prevent contamination [12–15]. Consequently, an alteration of the MG function has the potential to affect ocular surface homeostasis leading to dry eye symptoms

* Corresponding author at: Instituto Universitario de Oftalmobiología Aplicada (IOBA), Universidad de Valladolid, Paseo de Belén, 17, 47011 Valladolid, Spain.
E-mail addresses: mblancov@ioba.med.uva.es (M. Blanco-Vázquez), carroyoa@ioba.med.uva.es (C. Arroyo-Del-Arroyo), anovod@ioba.med.uva.es (A. Novo-Diez), pilarcanadas.s@gmail.com (P. Cañadas), albertolopezr@ioba.med.uva.es (A. López-de la Rosa), mjgonzalez@ioba.med.uva.es (M.J. González-García).

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[16].

MG morphology is habitually evaluated through subjective grading scales [5,7,12,17–19]. These scales have a lower sensitivity and more inter-observer and intra-observer variability than semi-objective or objective strategies [18,20,21]. In recent years, semi-objective and objective analysis, such as those performed with ImageJ or Phoenix software, have been used to assist the observer in quantifying the morphological parameters of the MG more accurately and objectively [20,22].

Long-term CL wear has been reported to alter both, MG function [11,12,17,18,23–25] and MG morphology [12,17,18,25]. A loss of MG function has a known negative impact on the tear film, being one of the main causes of ocular discomfort in CL wearers [12,16,26]. However, it is not clear whether an isolated alteration of MG morphology, i.e., one that occurs without an apparent clinical impact on MG function (meibum quality and expressibility), may cause discomfort. Indeed, changes in MG morphology have been reported both with [18,27] and without [28] alterations in meibum quality and expressibility, suggesting that morphological changes could induce functional changes that are currently unobservable with existing techniques. For this reason, the aim of this study is to analyse whether an alteration of MG morphology itself, assessed by a semi-objective software, can induce ocular discomfort in CL wearers without an apparent clinical alteration of MG function (meibum quality and expressibility).

2. Methods

This was a prospective, observational, case-control study approved by the University of Valladolid Ethics Committee (Valladolid, Spain). The study complied with the tenets of the Declaration of Helsinki and the International Conference on Harmonization Good Clinical Practices. Participants were informed about the study and written consent was obtained prior to their participation in the study.

2.1. Participant sample

Three groups of participants were recruited: 1) symptomatic CL wearers, 2) asymptomatic CL wearers and 3) non-CL wearers. The inclusion criterion for CL wearers was being soft CL wearers for at least 6 months prior to the study visit. Participants with symptoms of CL discomfort were considered to have a Contact Lens Dry Eye Questionnaire-8 (CLDEQ-8) score $\geq$ 12 [29]. Non-CL wearers should have no previous history of CL wear.

The exclusion criteria for all participants were: age under 18 years, extended or continuous CL wear, rigid gas-permeable CL wear, active ocular disease, history of a previous ocular surgery, use of topical medication other than artificial tears, and systemic disease that contraindicated CL wear. Additionally, participants with dry eye disease or abnormal MG function were excluded. Participants were considered to have dry eye disease when the Ocular Surface Disease Index (OSDI) score was $\geq$ 13 and at least two of the following conditions were present (in at least one eye): fluorescein tear break-up time (TBUT) $\leq$ 7 s, fluorescein corneal staining extension $\geq$ grade 2 according to the Cornea and Contact Lens Research Unit (CCLRU) scale in any area of the cornea, and Schirmer I test without anaesthesia $\leq$ 5 mm after 5 min [30]. MG function was considered abnormal when the quality and expressibility of lipid secretion were $>$ 1 according to the Shimazaki et al. scale [31–33].

2.2. Clinical examination

Participants were evaluated in a single visit. CL wearers were instructed not to wear their CLs for at least 24 h prior to the visit. Firstly, clinical history was taken and then the following clinical evaluation was performed.

2.2.1. Symptom evaluation

All participants were instructed to complete the OSDI questionnaire considering the symptoms they had suffered without CLs in the last week. The OSDI questionnaire consists of 12 questions that assess symptoms related to dry eye and their impact on vision [34]. The OSDI score ranges from 0 to 100, with a diagnostic cut-off $\geq$ 13 [35]. Moreover, CL wearers filled out the CLDEQ-8 considering the symptoms they had experienced while wearing CLs in the last two weeks. The CLDEQ-8 is an 8-item questionnaire that evaluates the symptoms of CL discomfort. The diagnostic cut-off for the CLDEQ-8 is $\geq$ 12 (total range 1–37) [29].

2.2.2. Clinical signs

TBUT and corneal staining were evaluated using sodium fluorescein strips (BioFluoro, Tiedra farmacéutica S.L, Madrid, Spain), a cobalt blue filter on a slit-lamp biomicroscope (SL-D7, Topcon Corporation, Tokyo, Japan) and a Wratten #12 yellow filter (Eastman Kodak Company, New York, USA). Three TBUT measures were taken, and the average was calculated. CCLRU grading scale (0–4) was used for assessing the extent of central, superior, inferior, nasal and temporal corneal staining, and the sum of the five areas was calculated (0–20) [36]. Schirmer I test (Tear Strips, Care Group, Gujarat, India) without anaesthesia was carried out to evaluate tear production.

Regarding MG function, quality and expressibility of meibum secretion was evaluated by applying digital pressure on the eyelids and was graded according to the following scale: 0 = clear meibum, easily expressed; 1 = cloudy meibum, easily expressed; 2 = cloudy meibum expressed with moderate pressure; 3 = meibum not expressible, even with hard pressure [31–33].

2.2.3. Meibography

Images of tarsal conjunctiva of the upper and lower eyelids were taken using a custom-made infrared non-contact meibography system to evaluate MG morphology. The eyelids were everted ensuring that at least the central 2/3 area of each eyelid was exposed. A slit lamp, an infrared device video camera (SUNLUXY® 420TVL CCTV Camera, model SL-C221, China) and a video transmitter (GRABSTER AV 350 MX and MAGIX Video easy, Terratec, Germany) were used to capture MG images. Images were then processed (contrast enhanced, Fig. 1) and analysed using ImageJ software, whose repeatability and reliability have been demonstrated [20,22,37]. First, the central 2/3 area of the eyelid was determined. The total horizontal length of the eyelid was measured in pixels, then 1/6 of that length was traced from the medial and lateral canthi of the eyelid toward the centre to obtain the central 2/3 area. The following parameters were then analysed in this area by a masked observer: number of MG, number of partial MG, percentage of MG tortuosity and percentage of MG loss (Fig. 2). Partial MG were considered to be those that did not reach the fornix (Fig. 1). MG tortuosity was estimated as the percentage of tortuous MG in relation to the number of MG. MG were considered tortuous when the duct had at least 1 curvature (Fig. 1) [38].

2.3. Statistical analysis

The R statistical package (version 4.1.2) was used to perform the statistical analysis of the data. Sample size was estimated to detect a significant difference of at least 10 % in the percentage of MG loss using the analysis of variance (ANOVA) for 3 groups and considering the standard deviation of CL wearers reported by Pucker et al. (10.6) [39]. Establishing a significance level of 0.05 and a statistical power of 80 %, at least 18 participants were needed in each study group. Both eyes were evaluated, although one eye was considered for analysis. The most symptomatic eye was chosen for the symptomatic CL wearers (it was considered on the basis of the participant's response), and a random eye was chosen for the groups of asymptomatic CL wearers and non-CL wearers.

For comparisons between two groups, independent samples *t*-test

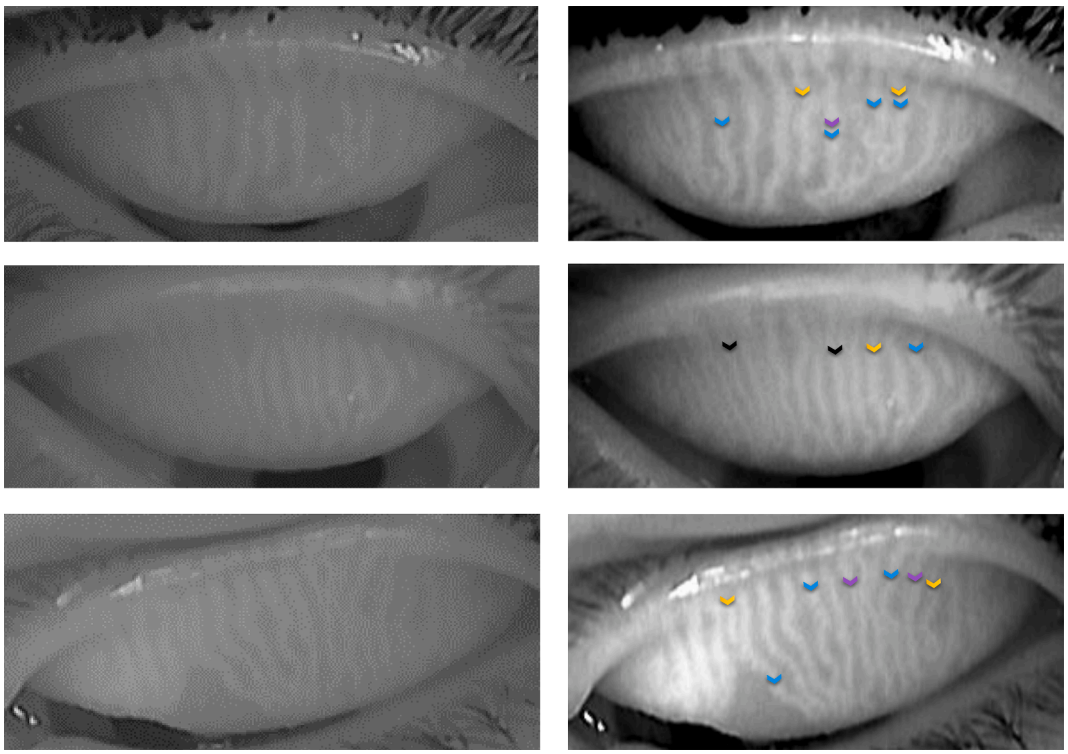

Fig. 1. Partial (yellow arrows), complete (purple arrows), tortuous (blue arrows) and non-tortuous (black arrows) meibomian glands are represented. Unprocessed images are shown on the left, and images processed with ImageJ software are shown on the right.

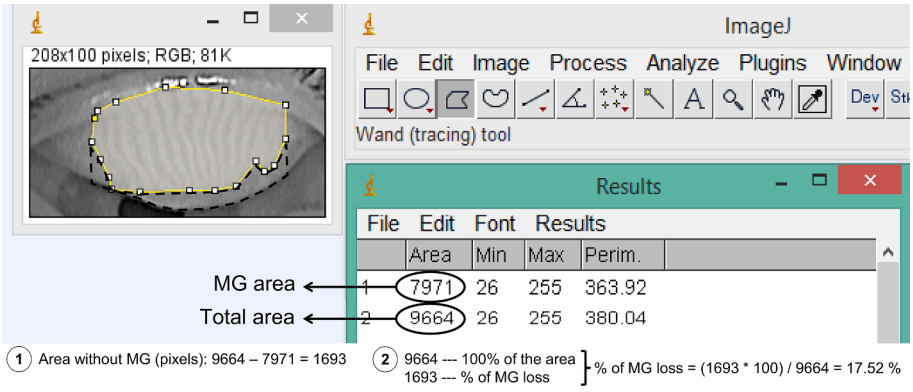

Fig. 2. Example of the measurement of the percentage of meibomian gland (MG) loss in the upper eyelid with ImageJ software. The yellow solid line with square markers represents the MG area, and the black dashed line represents the area of MG loss.

was used for normally distributed quantitative variables and Mann Whitney *U* test was employed for non-normally distributed quantitative variables. For comparisons among three groups, quantitative variables were analysed using one-way ANOVA (when normality was assumed) and Kruskal-Wallis H test (when normality could not be assumed), while ordinal and nominal variables were assessed with Kruskal-Wallis H and Chi-square tests, respectively. Post-hoc pairwise comparisons were assessed by Tukey test for normally distributed quantitative variables, or the Nemenyi test for non-normally distributed quantitative variables and ordinal variables. P-values $\leq$ 0.05 were considered statistically significant.

The relationship between CL discomfort (CLDEQ-8 score) and each MG morphology parameter of each eyelid was analysed using the Spearman correlation coefficient (rho). In addition, multivariable linear regression models were fitted for each eyelid including the CLDEQ-8 as the dependent variable and the four MG morphology parameters as the independent variables. A backward elimination method using a p-value threshold of 0.05 was used for variable selection. The lack of multicollinearity was checked by calculating the variance inflation factor (VIF $<$ 5), and the assumptions of linearity, normality, homoscedasticity, and lack of outliers were checked using the residuals of each fitted model. Correlations and multivariable regression models were performed for all CL wearers, as well as for symptomatic CL wearers separately. P-values $\leq$ 0.05 were considered statistically significant.

3. Results

3.1. Participants

Sixty volunteer participants (38 females and 22 males) with a mean age of 23.8 $\pm$ 6.3 (range 18–58) years were recruited and divided into three groups: 19 symptomatic CL wearers, 19 asymptomatic CL wearers and 22 non-CL wearers. Descriptive data for the study groups are summarized in Table 1.

Table 1
Descriptive data for the study groups.

Variables	Symptomatic CL wearers	Asymptomatic CL wearers	Non-CL wearers	P-value
Age (years)	22.5 ± 4.8 (18.0–35.0)	24.6 ± 5.4 (19.0–39.0)	24.2 ± 8.0 (19.0–58.0)	0.210
Sex (%female / %male)	73.7 / 26.3	57.9 / 42.1	59.1 / 40.9	0.525
Duration of CL wear (years)	5.9 ± 3.9 (0.5–15.0)	8.2 ± 4.5 (0.7–20.0)	—	0.117
CLDEQ-8 (range, 1–37)	21.8 ± 4.9 (14.0–30.0)	7.2 ± 2.7 (0.0–11.0)	—	***< 0.001***
OSDI (range, 0–100)	14.2 ± 9.9 (2.3–38.6)	6.1 ± 5.4 (0.0–18.2)[a]	6.5 ± 6.4 (0.0–22.0)[b]	***0.003***
TBUT (s)	9.4 ± 6.0 (3.7–27.3)	12.0 ± 6.1 (4.0–29.0)	12.6 ± 7.2 (3.3–27.0)	0.222
Corneal staining (range, 0–20)	0.4 ± 0.7 (0.0–2.0)	0.7 ± 1.0 (0.0–3.0)	0.4 ± 0.7 (0.0–2.0)	0.697
Schirmer test (mm)	19.0 ± 11.2 (5.0–36.0)	23.3 ± 11.6 (7.0–35.0)	24.7 ± 11.0 (3.0–37.0)	0.540
Quality and expressibility of lipid secretion (range, 0–3)	0 [0,1]	0 [0,1]	0 [0,1]	0.857

Numerical variables are presented as mean ± standard deviation (minimum–maximum), ordinal variables are presented as median [interquartile range], and nominal variables are presented as percentage. [a] P-value = 0.004 compared to symptomatic CL wearers. [b] P-value = 0.003 compared to symptomatic CL wearers. CL: contact lens; CLDEQ-8: Contact Lens Dry Eye Questionnaire-8; OSDI: Ocular Surface Disease Index; TBUT: tear break-up time.

3.2. MG morphology

Significant differences were found in the number of MG in the lower eyelid, with the group of symptomatic CL wearers having the least number of MG (Table 2). However, no significant differences were found in post-hoc pairwise comparisons ($p \geq 0.062$). Regarding the upper eyelid, borderline differences were obtained in the number of MG and the number of partial MG, with higher values in the group of symptomatic CL wearers.

3.3. Relationship between CL discomfort and MG morphology

A significant positive correlation was found between the CLDEQ-8 and the number of MG in the upper eyelid considering all CL wearers (rho = 0.47, p = 0.003). In the symptomatic CL wearers, the CLDEQ-8 significantly correlated with the number of partial MG (rho = 0.49, p = 0.034) and the percentage of MG loss (rho = 0.61, p = 0.005), both in the lower eyelid. No other significant correlations were found (Table 3).

Linear regression models were fitted for all CL wearers in the lower ($R^2 = 0.19$; p = 0.007) and upper ($R^2 = 0.19$; p = 0.001) eyelids as well as for the symptomatic wearers in the lower eyelid ($R^2 = 0.30$; p = 0.016). However, none of the variables were significant during variable selection for symptomatic wearers in the upper eyelid, then, no model could be fitted. The coefficients of the models constructed for all CL wearers and symptomatic wearers are shown in Table 4.

Table 2
Parameters of meibomian gland (MG) morphology.

Variables	Symptomatic CL wearers	Asymptomatic CL wearers	Non-CL wearers	P-value
Lower eyelid				
Number of MG	10.2 ± 2.0 (7.0–15.0)	11.7 ± 2.0 (9.0–17.0)	11.6 ± 2.3 (8.0–17.0)	***0.041***
Number of partial MG	3.6 ± 3.4 (0.0–15.0)	3.9 ± 3.2 (0.0–13.0)	3.3 ± 3.6 (0.0–14.0)	0.451
Percentage of MG loss	10.0 ± 7.0 (0.9–30.7)	13.7 ± 13.4 (1.6–57.1)	8.7 ± 5.7 (1.4–24.7)	0.577
Percentage of MG tortuosity	21.8 ± 16.0 (0.0–55.5)	17.5 ± 14.3 (0.0–41.7)	26.4 ± 22.6 (0.0–77.8)	0.305
Upper eyelid				
Number of MG	14.8 ± 2.3 (11.0–19.0)	12.8 ± 2.8 (8.0–18.0)	13.9 ± 2.6 (8.0–19.0)	0.066
Number of partial MG	11.9 ± 2.9 (7.0–17.0)	9.9 ± 3.7 (3.0–16.0)	9.14 ± 4.2 (0.0–16.0)	0.056
Percentage of MG loss	17.3 ± 6.4 (6.4–28.9)	19.5 ± 10.7 (5.1–42.8)	15.9 ± 14.3 (1.6–70.2)	0.232
Percentage of MG tortuosity	64.9 ± 20.8 (35.3–94.1)	70.6 ± 22.8 (25.0–100.0)	60.6 ± 19.0 (12.5–90.9)	0.314

Data are presented as mean ± standard deviation (minimum–maximum).

4. Discussion

Alterations in MG function can affect the tear film, which may trigger symptoms of ocular discomfort [16]. Many authors agree on the impact of CL wear on the alteration of MG function and the consequent development of ocular symptomatology [11,18,23–25]. However, there is controversy about the relationship between the changes of MG morphology and discomfort in CL wearers. Additionally, many of the studies to date have analysed MG morphology using subjective grading scales, which have limited sensitivity and high intra- and inter-observer variability [18,20,21]. Therefore, the present study evaluated the relationship between CL discomfort and MG morphology, as assessed by semi-objective software, in participants without an apparent alteration of MG function (meibum quality and expressibility).

The results of this study showed differences in the number of MG of the lower eyelid when comparing the three study groups; however, significant differences disappeared in the post-hoc pairwise comparisons. In addition, no significant differences were found in MG loss, number of partial MG or tortuosity of the upper or lower eyelids, suggesting that CL wear itself does not impact MG morphology. This lack of significant differences between non-CL wearers and both groups of CL wearers in any of the MG morphology parameters agrees with some reports in the scientific literature. These studies analysed the MG loss with ImageJ software and subjective grading scales, tortuosity using a subjective scale, and density by counting the number of MG in 1 cm, finding no effect of CL wear on these parameters [24,39]. On the opposite, other studies have detected higher grades of MG loss in CL wearers [12,17,18,25]. Thus, given the discrepancies between the various studies and the lack of significant results in the present work, the effect of CL wear on MG morphology remains unclear.

In addition, the lack of significant differences between symptomatic and asymptomatic CL wearers in the four parameters of MG morphology has been reported in the literature. Specifically, several studies analysing MG morphology using subjective grading scales found no significant effect of MG loss, or tortuosity, of the upper and lower eyelids on either CL discomfort, or dropouts due to discomfort [7,19]. Conversely,

Table 3
Spearman correlation coefficients between the Contact Lens Dry Eye Questionnaire-8 and the MG morphology parameters.

Variables	All CL wearers	Symptomatic CL wearers
Lower eyelid		
Number of MG	−0.20 (p = 0.229)	0.10 (p = 0.680)
Number of partial MG	−0.02 (p = 0.903)	0.49 (p = ***0.034***)
Percentage of MG loss	−0.05 (p = 0.765)	0.61 (p = ***0.005***)
Percentage of MG tortuosity	0.12 (p = 0.454)	−0.22 (p = 0.370)
Upper eyelid		
Number of MG	0.47 (p = ***0.003***)	0.02 (p = 0.938)
Number of partial MG	0.26 (p = 0.115)	−0.27 (p = 0.265)
Percentage of MG loss	−0.18 (p = 0.278)	−0.28 (p = 0.253)
Percentage of MG tortuosity	−0.12 (p = 0.468)	0.25 (p = 0.303)

Data show the Spearman correlation coefficient (rho) and its corresponding p-value. CL: contact lens; MG: meibomian gland.

Table 4
Coefficients of the multivariable linear regression models for all contact lens (CL) wearers and symptomatic CL wearers.

Variables	Unstandardized coefficients (95 % CI)	Standardized coefficients (95 % CI)	P-value
All CL wearers, lower eyelid ($R^2 = 0.19$; $p = 0.007$)			
Intercept	34.66 (21.23/48.08)		***0.001***
Number of MG	−1.93 (−3.19/−0.679)	−4.27 (−7.04/−1.50)	***0.004***
Number of partial MG	2.61 (1.22/4.00)	8.81 (4.12/13.5)	***0.001***
Percentage of MG loss	−0.747 (−1.15/−0.35)	−6.94 (−10.64/ −3.24)	***0.001***
All CL wearers, upper eyelid ($R^2 = 0.19$; $p = 0.001$)			
Intercept	−4.07 (−17.39/9.24)		0.539
Number of MG	1.34 (0.40/2.29)	1.24 (1.06/6.09)	***0.007***
Symptomatic CL wearers, lower eyelid ($R^2 = 0.30$; $p = 0.016$)			
Intercept	18.00 (14.34/21.67)		***<0.001***
Percentage of MG loss	0.38 (0.08/0.69)	2.70 (0.57/4.82)	***0.016***

CI: confidence interval; MG: meibomian gland.

Siddireddy et al. [5] observed greater MG loss in symptomatic CL wearers compared to asymptomatic CL wearers. These discrepancies might be explained by alterations in MG function which, although undetected by traditional clinical methods, are due to morphological changes. This suggests the hypothesis that a change of MG morphology, without clinically apparent alteration of MG function, can be a potential cause for CL discomfort.

The findings of the present study did show some significant relationships between CL discomfort and MG morphology. Nonetheless, some of the results found appear to be unhelpful. Particularly, a higher number of MG in the upper eyelid was associated with a higher CLDEQ-8 score, in the whole group of CL wearers. However, when symptomatic wearers were analyzed separately, this counterintuitive result disappeared. Given the lack of, or minimal, symptoms expected in the asymptomatic wearers, whose range of CLDEQ-8 scores varied between 0 and 11, the resulting data might be the result of chance and so, should be interpreted with caution.

In the lower eyelid, a linear combination of MG morphology parameters (number of MG, number of partial MG and percentage of MG loss) appears more useful for explaining CLDEQ-8 score in all wearers. It may also indicate that the morphology of lower eyelid is more likely to drive the pre-clinical changes that affect discomfort responses.

For symptomatic wearers, CLDEQ-8 showed univariate positive correlations with the number of partial MG and the percentage of MG loss in the lower eyelid, but only the percentage of MG loss remained in the multivariable regression model. The reason why the number of partial MG was not included in the model was likely to be that it quantifies a similar characteristic to percentage MG loss, with the latter being more detailed.

Other studies have also reported relationships between ocular symptomatology and MG morphology. In particular, a positive correlation has been reported between ocular symptoms, assessed by the OSDI questionnaire, and MG loss in CL wearers and/or non-CL wearers [24,40–42]. It also appears relevant that the symptomatology of CL wearers is known to improve with MG treatments, such as eyelid hygiene and intense pulsed light, with some authors even reporting that MG loss (evaluated by software and subjective grading scales) decreases in such circumstances [43–45]. All these findings support the idea that CL-related symptomatology is associated with MG loss, at least.

It is also interesting to note that the relationship between MG morphology and CL discomfort was different between eyelids, with lower lid morphology being the best predictor of symptomatology. Crespo-Treviño et al. also showed no differences in upper lid, MG morphology between healthy and dry eye disease subjects [46] and other authors have reported MG loss to be higher in lower eyelids than upper eyelids [47–49]. As a possible explanation for the differences between eyelids, Eom et al. [47] hypothesized that pronounced movements of upper eyelids during blinking facilitate the secretion of meibum, which could prevent MG loss. Conversely, greater changes in the upper eyelid have been found and attributed to increased friction between the lid and ocular and CL surfaces relative to the lower eyelid [5,17].

Given this uncertainty, both eyelids should be assessed, since the morphology may differ [28,50] and in CL wearers, the lower eyelid may require more detailed observation because of its relationship with ocular discomfort.

The present study has some limitations. It had a cross-sectional design which did not allow investigation of the cause-effect relationship between CL discomfort and MG alterations. Longitudinal studies in neophytes, before and after CL wear, are needed, although the relationship may be complex as it is not possible to predict the development of CL discomfort. Additionally, the mean age of the participants was younger than that of CL wearers in general [51]. This may be a consequence of excluding those with evident alteration of MG function, which is known to increase with age [13,15]. On the other hand, this will have tended to diminish the inclusion of age-related confounding risk factors, such as MG dysfunction [52]. No differences in age, gender or years of CL wear were found among groups.

The most symptomatic eye was chosen for analysis, based on the assumption that this would mainly influence the global subjective opinion as measured by questionnaires (which consider both eyes together). This influence was considered irrelevant for asymptomatic wearers, given that little or no symptomatology is expected. Nonetheless, it is remarkable that 17 of the 19 symptomatic wearers did not indicate a preference and the study eye was then selected randomly. Therefore, the effect of this selection is likely to be minimal.

In conclusion, the results of this study suggest that an alteration of the MG morphology alone, i.e., without clinically apparent alteration of MG function (meibum quality and expressibility), can potentially be responsible for CL discomfort. Further, once discomfort appears, MG loss may play a role in the degree of CL-related symptoms. MG alteration of the lower and upper eyelids may be different and while it is important to monitor both eyelids, in CL wearers the lower eyelid may be particularly useful in showing changes that lead to the onset of symptoms.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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