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Clinical factors associated with contact lens dropout

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ABSTRACT

Purpose: Contact lens (CL) dropout is estimated to be approximately equal to the number of new wearers per year, resulting in virtually no growth in the global CL market. The purpose of this study was to determine ocular and CL factors associated with CL dropout.
Methods: This five-site study recruited subjects 18–45 years of age who had ceased CL wear within the past 6–12 months due to discomfort. Dropout subjects were compared to age- and sex-matched currently successful CL wearers. Each subject was administered a symptoms survey and a study-specific survey that queried general CL history and compliance. Clinical testing included non-invasive tear break-up time, tear meniscus height, blepharitis assessment, meibum quality and expression, and meibography.
Results: A total of 56 matched-pairs were recruited. Dry eye was found to significantly increase a subject's odds of dropping out of CLs. The odds of dropping out of CLs was also significantly increased with each worsening grade of upper or lower eyelid meibomian gland (MG) plugging, upper eyelid meibum quality, and upper eyelid MG tortuosity. No other factors analyzed increased a subject's odds of dropping out of CLs.
Conclusions: CL dropout may be precipitated by underlying dry eye symptoms, though most dry eye signs, with the exception of MG structure and function, had minimal predictive value for CL dropout. Nevertheless, evidence suggests that practitioners should screen for and educate CL patients about the importance of maintaining healthy MGs, which may potentially allow them to maintain comfortable CL use and increase their CL longevity.

1. Introduction

Contact lens (CL) comfort and wearability is of great concern to the millions of patients who wear CLs, and, of course, also to the manufacturers who design these products [1]. Contact lenses are the ideal vision correction choice for some individuals because CLs allow them to achieve better, less restricted vision, allow for an increased ability to play sports and perform work tasks, and provide patients with a better perceived cosmetic appearance than spectacles [1,2]. Nevertheless, past research has indicated that 21%–64% of CL wearers discontinue CL use because of ocular discomfort, while others are able to continue wearing their CLs well into their presbyopic years [3–7]. If we understand the differences leading to Contact Lens Discomfort (CLD) in some patients, but not in others, we would then have the knowledge to better treat patients who have CLD, which is a condition characterized by decreased ocular comfort related to CL use, decreased CL wear time, and ultimately, if measures are not taken, CL dropout [8].

Investigators have long compared differences between CL wearers and subjects who have never worn CLs to understand if there is a negative impact associated with wearing CLs [9–14]. For example, some investigators have found that there are minimal differences in meibomian gland (MG) atrophy between successful CL and non-CL wearers [12,14]; however, others have found that CL use may promote MG dysfunction and/or MG atrophy [9,11–13]. Conflicting studies also make it unclear how habitual CL use affects other ocular signs such as pre-ocular tear break-up time and tear meniscus height [9–14], and it is currently unclear how CL wear schedule, CL care systems, and CL compliance impacts CL dropout.

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Past work from the Contact Lens Assessment of Symptomatic Subjects (CLASS) study group suggests that these conflicting results may stem from survivor bias; they specifically were unable to detect a MG atrophy rate that was significantly different from zero when analyzing age or years of CL wear in a group of healthy, pre-presbyopic CL wearing adults [15]. This study likewise failed to find a significant different in MG atrophy rates when comparing these same healthy CL wearers to age- and sex-matched asymptomatic non-CL wears [15]. This unexpected result seems unlikely since MG atrophy increases with age [16]. Essentially, these data suggest that only people who do not develop significant MG atrophy are able to sustain CL wear. If this is correct, then it would be reasonable to conclude that healthy MGs are required for successful CL use.

Therefore, the purpose of this experiment was to study the phenomenon itself, discomfort induced-CL dropout, by conducting a multicenter study on subjects who have previously dropped out of CLs within the past six to twelve months because of discomfort. Cases were then compared to age- and sex-matched successful CLs wearers in order to firstly determine what CL factors are associated with CL dropout, secondly determine what ocular factors are associated with CL dropout, and finally determine if there was a survivor effect as in past MG atrophy studies. This information can be used to better understand CL dropout and to help elucidate information that might allow for the development of better CLs and care systems that help target/influence these factors.

2. Methods

2.1. Subjects

This was a prospective, single-visit study, and participants were recruited across five clinical study sites (University of Alabama at Birmingham, University of Waterloo, Marshall B. Ketchum University, JENVIS Research c/o Ernst Abbe University of Jena, and University of Houston). Subjects between 18 and 45 years of age who had completed a comprehensive eye exam within the past two years were recruited. Subjects older than 45 years of age were excluded to decrease the likelihood that they dropped out of CLs for vision reasons due to presbyopia. Subjects who self-reported that they discontinued CL wear within the past six to twelve months, because of discomfort, were enrolled; this small window of time was intended to allow for a more direct comparison between groups and to ensure that ocular changes did not occur since the time of dropout. CL dropouts were compared to successful CL wearers (≥ 8 h/day, ≥ 5 days/week, Contact Lens Dry Eye Questionnaire (CLDEQ)-8 scores ≤ 10) [17]. Subjects were excluded if they had ever worn gas permeable or specialty hard CLs, had used artificial tears or rewetting eye drops within two hours of the study visit, had a systemic health conditions known to alter tear film physiology (e.g., primary and secondary Sjögren's syndrome), had a history of ocular surgery within the past twelve months, had a history of severe ocular trauma, active ocular infection or inflammation, were currently using Accutane or ocular medications, or if they were pregnant or breast feeding [18]. Subjects with a condition or in a situation which, in the examiner's opinion, may have put the subject at significant risk, may confound the study results, or may had significantly interfered with their participation in the study were also excluded. Subjects with non-Sjögren's dry eye disease and subjects who had mild corneal scarring (no corneal elevations changes and acuity better than 20/40) were allowed to participate.

2.2. Statistical analysis and sample size

Meibomian gland atrophy (measured as meiboscore) was used as the primary clinical outcome measure, on which the two cohorts were compared. Data from Arita et al. were used to obtain estimates of variability in meiboscores (defined below) [16]. Sample size calculations were performed using PASS 2005 assuming a two-sided *t*-test with alpha = 0.05 and beta = 0.10 (90% power). The aim was to observe a difference between the two cohorts that was similar to that of our previous study on MG atrophy (effect size = 0.55) [14]. Thus, 37 subjects in each arm (74 total subjects) were required to make a comparison between the CL dropouts and successful CL wearers.

A secondary goal was to gain a preliminary understanding of potential associations between MG atrophy and soft CL factors such as CL replacement schedules, CL materials, CL care systems, and years of CL wear. Market data from *Contact Lens Spectrum* (PentaVision LLC, Ambler, PA, USA) was used to develop a sample size estimate that was able to determine how monthly (45%), two week (26%), and daily disposable (28%) CLs were associated with MG atrophy [1]. Assuming half of the CL wearers and CL dropouts were on a monthly replacement schedule, a sample size of 112 was needed to allow us the power to assess this relationship for a similar effect size (0.55) at a power of 80%. This sample size also provides some information about how CL care systems (hydrogen peroxide vs. multipurpose) and CL materials (hydrogel vs. silicone hydrogel) were related to MG atrophy (both roughly 20% vs. 80% of market) [1].

2.3. Study protocol

Subject pairs were competitively enrolled across sites. Subjects were screened for eligibility to ensure that, above all, all cases had dropped out of CLs within the past six to twelve months because of discomfort based upon Young et al.'s list of reasons for dropping out of CLs (1. Discomfort, 2. General Poor Vision, 3. Poor Reading Vision, 4. Difficulty with Handling, 5. Advised by Practitioner, 6. Inconvenient, 7. Eyes were Red, 8. Lost Interest, 9. Too Costly, 10. Reaction to Care Products, 11. Lost Lenses, 12. Other) [4]. These subjects were then age- and sex-matched to CL wearers who had minimally symptomatic CLDEQ-8 scores (scores ≤ 10) [17]. CL wearers were asked to report to the study without their CLs to avoid detection of any transient ocular surface changes; this also allowed for a more direct comparison of the two study groups.

Eligible subjects were enrolled, consented, and requested to sign a health privacy document if deemed appropriate by the study site. Each site was approved to conduct this study by their respective Human Subjects Institutional Review Board, and this study was performed in accordance with the Declaration of Helsinki. Measurements were obtained from both eyes of each eligible subject and testing was performed in the below order. Testing order was sequentially administered from the least invasive to most invasive test, a methodology that helped to ensure that a previous procedure had a minimal effect on all subsequent assessments [19]. All relevant ocular, systemic, and CL history were then gathered via an investigator-developed questionnaire.

All subjects were instructed to complete the Standardized Patient Evaluation of Eye Dryness (SPEED) questionnaire, as it has been shown to be repeatable and inquiries about the most common dry eye symptoms [20,21]. A multifunctional topographer (Keratograph 5 M, Oculus, Inc., Wetzlar, Germany) was used to determine the subject's non-invasive tear break-up time by focusing the machine on the patient's tear film and then using a stopwatch to record the amount of time in seconds before the first distortion appeared on the array of Placido disk rings (~ 64 mm^2 field of view); the mean of three measurements by eye were used in analysis [14]. The same instrument was then used to determine the subject's tear meniscus height directly below the pupil; the mean of three independent measurements by eye were used in analysis [14]. Next, the investigator used a slit-lamp biomicroscope to document blepharitis with a grading scale that was developed by the investigators. Meibomian gland expressibility and quality were evaluated for each eyelid, upper and lower. The central 8 meibomian glands were expressed with the investigator's finger by placing it about one millimeter below the inferior lash line and applying light pressure for 15 s, and meibum and expression were graded per Meadows et al.'s grading scale

Table 1
Summary of Subjective Grading Scales.

Test	Descriptions				
Blepharitis [14]					
Scale	0	1	2	3	4
Number of Collarettes	None	1–5	6–20	21–40	> 40
Number of Plugged Meibomian Glands [22]					
Scale	0	1		2	3
Number of Plugged Glands	None	1–2		3–4	≥5
Meibum Quality [22]					
Scale	0	1	2	3	4
Meibum Quality	Clear	Granular	Semisolid	Solid	None Expressed
Meibomian Gland Atrophy (Meiboscore) [16]					
Scale	0	1		2	3
Percentage of Gland Loss	None	1 to < 33		33 to 67	> 67
Meibomian Gland Tortuosity [24]					
Scale	0	1	2	3	4
Percentage of Tortuous Glands	None	< 25	26 to 50	51 to 74	> 75

[22]. Meibomian glands (meibography) were imaged with the multifunction topographer by everting the upper and then lower eyelids with a cotton-tipped applicator [23]. Two masked examiners graded the amount of meibomian gland atrophy present with a 0–3 meiboscore grading scale (Grade 0 = no atrophy; Grade 1 = < 33% of MGs lost; Grade 2: 33%–67% of MGs lost; Grade 3 = > 67% of glands lost) and the amount of meibomian gland tortuosity present with a 0–4 grading scale (Grade 0 = 0% of MGs tortuous; Grade 1 = < 25% of MGs tortuous; Grade 2 = 26%–50% of MGs tortuous; Grade 3 = 51%–74% of MGs tortuous; Grade 4 = > 75% of MGs tortuous) after the completion of the study [16,24]. Discordant examiner scores were re-graded by a third examiner, and any remaining discordant grades were resolved through discussion by the original two examiners. Subjects were considered to have diagnosed dry eye if they had a SPEED score > 5.0 and a positive NITBUT (< 10 s) or TMH (< 0.2 mm) test [25]. A summary of all subjective grading scales can be found in Table 1.

2.4. Data analysis

The worse eye, based upon atrophy, was used in analysis because the authors hypothesized that the worse eye was most likely to drive symptoms and CL dropout. All data analyses were completed with SAS Version 9.3. The outcome of this case-control study was CL drop-out or not. Because subjects were 1:1 matched on age (± 3 years) and sex between current CL wearers and CL dropouts, all analyses incorporated this clustering. Descriptive statistics such as mean and standard deviation were used to describe the data. Paired t-tests were used to investigate differences between the two groups on the continuous covariates (e.g. number of years of CL wear, tear meniscus height). For categorical variables, such as type of CL material worn and type of CL care system used comparisons of the matched groups was achieved using McNemar's test for 2 × 2 tables and Bowker's Test of Symmetry for *n x n* tables.

Because of the matching, the standard (unmatched) approach to analyzing these data would produce biased estimates [26]. A conditional logistic regression model was fit to account for the matched pair nature of the data while controlling for covariates, if any, were identified. Models were built incorporating the matched pairs as stratum and evaluating the factors of interest listed above. Univariate models were completed first, and from the statistically significant variables (set at $p < 0.10$ for entry) multivariate models were tested. Independent variables such as meiboscore, MG plugging, and meibum quality were assessed in several different ways to determine the best model fit. This was accomplished by assessing continuous variables in a categorical and dichotomous fashion as well. The best fit among these models, judged by maximizing the -2 Log likelihood, was used for the multivariate analyses. Variables were added in a step-wise fashion to determine the impact on the model. The final model retained those variables that were significantly related to CL dropout status ($p < 0.05$). From these models, we were able to obtain the matched adjusted (for covariates) odds ratios, which represents the associations with CL dropout status. For example, an Odds Ratio (OR) greater than one indicates that the covariate of interest was more associated with CL dropout.

3. Results

3.1. Contact lens factors associated with contact lens dropout

This study recruited 56 matched-pairs across sites. The mean ± SD age of the successful CL wearers (28.5 ± 7.1 years) and the CL dropouts (28.6 ± 7.0 years) were similar (p = 0.66). The sample was 60.7% female.

Successful CL wearers had worn CLs for 10.86 ± 6.52 years while CL dropouts had worn CLs for 7.82 ± 6.74 years (p = 0.01) (Table 2). There was no difference in the age at first CL wear (p = 0.19), although successful CL wearers had worn CLs for nearly 3 years longer overall than the CL dropouts (p = 0.01) (Table 2). Over two-thirds of the CL dropouts reported wearing their CLs ≤ 4 days per week before dropping out of CLs while nearly the same proportion of the successful CL wearers wore their CLs 6–7 days per week ($p < 0.001$) (Table 2). CL dropouts also had a shorter average wear time by at least 2 h per day compared to successful CL wearers ($p < 0.001$) (Table 2).

Lens modality (daily, biweekly, or monthly replacement), primary CL solution type used (hydrogen peroxide vs. multipurpose solution), multipurpose solution preservative disinfection used (polyquaternium-1-containing vs. polyhexamethylene biguanide-containing), CL or case exposure to tap water, on-time CL replacement, CL case replacement at least every 3 months, sleeping in CLs, or wearing a pair CLs beyond the clinician-recommended timeframe were not associated with CL dropout (all p ≥ 0.41) (Tables 2 and 3). Although borderline significant, the odds of CL dropouts having worn a conventional hydrogel CL (rather than a silicone hydrogel) was higher than for a successful CL wearer (OR = 2.5, p = 0.05). Successful CL wearers napped more often in their CL than CL dropouts (p = 0.01), and CL dropouts were more likely to use artificial tears or rewetting drops with their CLs than successful CL wearers (p = 0.01) (Table 3).

Table 2
Contact Lens Factors by Subject Group.

Compliance Factor	Contact Lens Wearers (Mean ± SD)	Contact Lens Dropout (Mean ± SD)	P-Value
Age at First Contact Lens Use (Years)	17.27 ± 6.72	18.68 ± 5.50	0.19
Total Contact Lens Use (Years)	10.86 ± 6.52	7.82 ± 6.74	0.01
Wear Time Per Day (Hours)	13.47 ± 2.92	11.20 ± 3.56	< 0.001
Days of Contact Lens Use (Days/Week) (%)			
≤4 days	1.8	67.3	< 0.001
5 days	23.6	9.1	
6 days	30.9	5.5	
7 days	43.6	18.2	
Primary Contact Lens Solution (%)			
Hydrogen Peroxide	12.1	9.1	0.65
Multipurpose Solution	87.9	90.9	
Multipurpose Solutions Disinfectant (%)			
Polyquaternium-1-containing solutions	47.8	43.5	0.95
Polyhexamethylene Biguanide (PHMB)-containing solutions	52.2	56.5	
Contact Lens Wear Schedule (%)			
Daily Disposable	36.5	38.5	0.53
Biweekly	26.9	17.3	
Monthly	36.5	44.2	
Contact Lens Material (%)			
Hydrogel	11.5	28.8	0.05
Silicone Hydrogel	88.5	71.2	

3.2. Ocular factors associated with contact lens dropout

CL dropouts had significantly higher symptom scores from the SPEED questionnaire than successful CL wearers (6.42 ± 4.96 vs. 2.62 ± 2.66; $p < 0.001$). Mean non-invasive tear break-up time, tear meniscus height, and upper, lower and total MG atrophy were not different between groups (all $p \geq 0.24$) (Table 4). Upper ($p < 0.001$) and lower ($p = 0.04$) MG plugging and upper ($p < 0.001$), but not lower ($p = 0.26$) meibum quality was worse in CL dropouts (Table 4). Lower eyelid MG atrophy was not associated with upper or lower MG plugging or upper or lower meibum quality (all $p \geq 0.07$) while upper eyelid atrophy was associated with both gland plugging and meibum quality in both eyelids (correlations between 0.19 and 0.30). Successful CL wearers had significantly less upper eyelid MG tortuosity (1.41 ± 0.76 vs. 1.85 ± 1.10; $p = 0.01$), worse tortuosity in the lower eyelid (0.91 ± 0.75 vs. 0.69 ± 0.66; $p = 0.04$), and no difference in total (2.32 ± 1.21 vs. 2.53 ± 1.34; $p = 0.36$) eyelid MG tortuosity scores compared to CL dropouts. CL dropouts were significantly more likely to be diagnosed with dry eye than successful CL wearers (0.32 ± 0.47 vs. 0.05 ± 0.23; $p = 0.001$).

3.3. Predicting contact lens dropout

The odds of having dropped out of CLs significantly increased for each worsening grade for upper eyelid (OR = 4.95; $p = 0.0004$) and lower eyelid (OR = 1.65; $p = 0.05$) MG plugging as well as upper eyelid (OR = 2.73; $p = 0.005$) meibum quality. Upper eyelid MG tortuosity was associated with increased odds of being a CL dropout (OR = 1.74; $p = 0.02$), while lower eyelid tortuosity was associated with a decreased odds of being a CL dropout (OR = 0.47; $p = 0.05$). The odds of having dropped out of CLs significantly decreased by over

Table 4
Ocular Factors by Subject Group.

Test	Contact Lens Wearers Mean ± SD	Contact Lens Dropout Mean ± SD	P-Value
SPEED Score (units)	2.62 ± 2.66	6.42 ± 4.96	< 0.001
Diagnosed Dry Eye	0.05 ± 0.23	0.32 ± 0.47	< 0.001
Non-Invasive Tear Break-Up Time (seconds)	12.33 ± 8.14	11.36 ± 8.61	0.41
Tear Meniscus Height (mm)	0.30 ± 0.10	0.28 ± 0.10	0.24
Blepharitis			
Upper Eyelid (0–4 scale)	0.46 ± 0.66	0.71 ± 0.83	0.09
Lower Eyelid (0–4 scale)	0.20 ± 0.52	0.38 ± 0.65	0.09
Number of Plugged Meibomian Glands (0–3 scale)			
Upper Eyelid (0–3 scale)	0.64 ± 0.82	1.24 ± 1.01	< 0.001
Lower Eyelid (0–3 scale)	0.71 ± 0.93	1.06 ± 1.00	0.04
Meibum Quality			
Upper Eyelid (0–4 scale)	0.66 ± 1.00	1.37 ± 1.53	< 0.001
Lower Eyelid (0–4 scale)	0.68 ± 1.15	0.94 ± 1.20	0.26
Meibomian Gland Atrophy (Meiboscore)			
Upper + Lower Eyelid (0–6 scale)	2.13 ± 0.66	2.22 ± 1.05	0.57
Upper Eyelid (0–3 scale)	1.02 ± 0.30	1.05 ± 0.49	0.64
Lower Eyelid (0–3 scale)	1.11 ± 0.59	1.16 ± 0.76	0.66
Meibomian Gland Tortuosity			
Upper + Lower Eyelid (0-8 scale)	2.32 ± 1.21	2.53 ± 1.34	0.36
Upper Eyelid (0–4 scale)	1.41 ± 0.76	1.85 ± 1.10	0.01
Lower Eyelid (0–4 scale)	0.91 ± 0.75	0.69 ± 0.66	0.04

[*] Eye with worse meibomian gland atrophy was used in analysis.

Table 3
Contact Lens Compliance by Subject Group.

Compliance Factor	Contact Lens Wearers	Contact Lens Dropout	P-Value
Did you wear your contact lenses longer than doctor recommended? (Yes%)	24.1	20.4	0.66
Did you sleep in your contact lenses overnight? (Yes%)	16.1	10.7	0.41
Did you nap in your contact lenses? (Yes%)	62.5	37.5	0.01
Did you regularly expose your contact lenses or case to tap water? (Yes%)	21.4	17.9	0.64
Did you use artificial tears or rewetting drops with your contact lenses? (Yes%)	17.9	39.3	0.01
Did you replace your contact lens case more frequently than every three months? (Yes%)	67.9	50.9	0.06

3.3 if subjects napped in their CLs (p = 0.01). The odds of being a CL dropout were decreased if the subject did not have dry eye (OR = 0.12; p = 0.004). Years of CL wear (OR = 0.91; p = 0.01) and hours of CL wear (OR = 0.80; p = 0.004) were inversely associated with the odds of being a CL dropout. Attempts at multivariate modeling did not yield a model. Dry eye and MG plugging on the upper eyelid were the best fit models, individually, but using the two variables together did not produce a robust model, likely due to sample size.

4. Discussion

In order to determine factors that may lead to CL dropout, this study investigated the impact of CL related factors, CL compliance, and ocular signs and symptoms. The results of this study showed a mean CL use of 7.8 years before CL dropout. The initial age at first use of CLs was not correlated with successful CL wear as this was similar between both groups investigated. This is in contrast to Richdale et al. who found that starting CLs at a later age increased one's chances of dropping out of CLs, a difference that could be attributed to the current study only including recent CL dropouts who dropped out of CLs because of discomfort [27]. It was reported by former CL wearers, however, that they had worn CLs for significantly fewer days per week and fewer hours per day; this is consistent with past research and may be partially connected to the use of hydrogel CLs, which were borderline significantly more likely to be worn by CL dropouts (15 hydrogel vs. 37 silicone hydrogel CL wears) than comfortable CL wearers (6 hydrogel vs. 46 silicone hydrogel CL wears) (p = 0.05) [27]. This finding was corroborated by Dumbleton et al. who found in a group of 4207 subjects in an electronic survey of lapsed and non-lapsed CL wearers that non-lapsed wearers were more likely to wear silicone hydrogel CLs (rather than hydrogel CL) than lapsed wearers ($p < 0.001$) [28]. However, no firm consensus on whether silicone hydrogel CLs alone can ameliorate CL discomfort currently exists [7,29].

This study also found that uncomfortable CL wearers likely wish to improve their wearing experience. This is highlighted by how CL dropouts were significantly more likely to use artificial tears or rewetting drops than successful CL wearers. The usage of artificial tears or rewetting drops for symptom relief seems to be an easy conclusion drawn by CL wearers with dryness symptoms. Nevertheless, these subjects were still more likely to wear their CLs less and eventually drop out of CLs. One reason may be that the patients were simply not dosing the artificial tears or rewetting drops frequently enough to mitigate their symptoms. Another reason why the drops may not be adequately mitigating eye comfort issues may be due to formulation. This is highlighted by Guthrie et al. who found that a lipid-containing drop may have a bigger benefit regarding improved comfortable lens wearing time and dry eye signs than non-lipid containing drops [30].

Aside from self-treating with eye drops, many CL wearers could improve their ocular comfort by simply following lens replacement recommendations and using good lens care habits. It was shown in the current study that about 20% of the subjects in each group were using CLs longer than recommended or exposing their CLs or CL case to tap water. While these factors were not significantly different between groups, they may still be contributing to CL discomfort [31]. Likewise, a review by Wu et.al. found that 18% to 85% of CL cases were contaminated at any given time, a factor that is more likely to occur with increased case age [32,33]. While greater case age was more likely to result in a microbial keratitis event [34], the current study did not find case age to be significantly associated with CL dropout. Furthermore, the current study did not find an association between overnight night CL use and CL dropout; however, it did find napping in CLs to be 'protective' against CL dropout. Sorbara et al. previously found napping in CLs to also be protective against significant and serious events such as microbial keratitis [35]. While there is a chance that napping is truly protective against CL dropout or significant and serious events as reported by Sorbara et al., it is more likely that those in the CL dropout group were simply not wearing their CLs long enough on an average day or in total duration to have the opportunity to nap in their CLs or that napping itself may make the CLs feel uncomfortable to the point that these patient intentionally avoid napping in their CLs. Alternatively, the successful CL wearers may be more resilient than the CL dropout subjects, which subsequently may allow the successful CL group to more easily nap in their CLs. Nevertheless, hygiene and CL compliance are factors which contribute to successful CL wear and some of the above non-significant factors may still be non-precipitating factors contributing to CL dropout [36].

In addition to CLs and CL care systems habits, characteristics of multipurpose solutions, in particular, may influence successful CL wear. This point is emphasized by the potential causes of solution induced corneal staining (SICS) [37]. It has long been debated if the hyperfluorescence (SICS) associated with CL use is the result of multipurpose solution surfactant and/or disinfectant molecules being released from CLs and either inducing corneal epithelial cell death, which could cause hyperfluorescence, or if the hyperfluorescence is originating from within live cells [37–39]. While it has long been thought that disinfectant molecules are the primary culprit [38,39], recent research suggests, however, that a specific surfactants, Tetronic 1107, which is primarily found in PHMB-containing multipurpose solutions, is likely actively transported along with the fluorescein into corneal epithelial cells and resulting in the hyperfluorescence [37]. Multipurpose solutions are also likely to interact with the bulbar and palpebral conjunctiva and the meibomian glands. It was reported by Andrasko and Ryen that CL comfort can be decreased when using a polyhexamethylene biguanide (PHMB)-containing CL care system compared to one containing polyquaternium-1 [38]. Nevertheless, the current study failed to find a difference between type of care system (hydrogen peroxide vs. multipurpose) or the preservatives used in the multipurpose solutions with regards to being able to successfully wear CLs. This may appear surprising, as PHMB-based products have been previously linked to decreased comfort and decreased comfort is the top reason for permanently dropping out of CLs [3,6,40].

This study also focused on understanding ocular factors that may be associated with CL dropout. The current study accomplished this by minimizing the influence of not wearing CLs on ocular signs and symptoms in the CL dropout group by requiring the experimental group to have stopped wearing CLs within the past 6–12 months and then compared these subjects to successful CL wearers. The results of this study clearly showed a difference between the successful CL group and the CL dropout group with respect to the eyelid margin. This study specifically found that upper and lower MG expressibility, upper eyelid meibum quality and upper eyelid MG tortuosity are important for maintaining CL use; however, no other objective ocular surface measures were found to be significantly different between groups. Thus, a logical consequence of this work would be to recommend to patients that they undertake prophylactic eyelid hygiene, which has been shown by Guillon et al. and Lee et al. to improve eyelid appearance and meibum quality [41,42]. Furthermore, this recommendation should be made especially to CL wearers who have increased dryness symptom scores. This finding is corroborated by how the current study found significantly higher symptoms scores in the CL dropout group even after not wearing their CLs for 6–12 months compared to the successful CL wearers. This result highlights how validated symptoms questionnaires should be implemented in every CL practice to identify at-risk patients early and to quantify how symptoms change over time, so appropriate treatment measures can be taken to help promote comfortable CL use [21].

It is interesting to draw attention to how this study did not find a difference in MG atrophy between the two study groups since one of the hypotheses of this study was that CL-induced MG atrophy changes may be responsible for at least some of the ocular symptoms noticed by CL wearers, [43] which could subsequently be responsible for CL dropout [3]. This premise was at least partially based upon a study by Arita et.

al., who found significantly higher meiboscore (more atrophy) in CL wearers compared to non-wearers; atrophy scores in this study also increased with years of CL use and were independent of being a gas permeable or soft CL wearer [13]. Since Arita et al.'s seminal work, Alghamdi et al. were able to find an association between greater MG atrophy and CL use, though they concluded that CL-induced atrophy likely only happens within the first two years of use, and it does not progress after that time point [44]. Pucker et al. and Machalinska et al. have likewise employed an age- and sex-matched study design, which failed to find an association between CL use and MG atrophy [12,14]. Since the current study failed to find an association between MG atrophy and CL dropout, it is unlikely that there was a survival effect in Pucker et al.'s and Machalinska et al.'s studies, or if put another way, subjects with high amounts of atrophy were not selectively excluded from Pucker et al.'s and Machalinska et al.'s studies because they had already dropped out of CLs [12,14]. It is currently unclear why Arita et al.'s 2009 study found an association between CL use and MG atrophy while the others have failed to find an association. Nevertheless, it is possible that this difference could be related to Arita et al.'s study primarily recruiting Asian subjects [13], a race that likely has a genetic predisposition for dry eye [45]. This claim is at least partly supported by Asians subjects being more likely to have dryness symptoms compared to non-Asian subjects [45]. Although MG atrophy (structure) does not appear to be a precipitating factor for CL dropout, MG function does still appear to be important for comfortable CL use potentially because of the MG's contribution to tear stability [46]. This was demonstrated by CL dropouts being significantly more likely to have worse upper and lower eyelid meibomian gland expressibility and upper eyelid meibum quality than the successful CL wearers. These data overall suggest that normal meibomian gland health is needed to support CL use.

Overall, the information obtained from this study adds to our understanding of CL comfort, and it will allow us to advise practitioners as to what signs are associated with comfortable CL wear. This study specifically found that CL care and compliance had minimal impact on the ability to successfully wear CLs while ocular factors such as meibum expressibility, meibum quality, and meibomian gland tortuosity may serve as warning signs for CL dropout. The data overall suggest that proactively treating meibomian gland dysfunction with eyelid hygiene may promote ocular comfort and additional years of comfortable CL use. Nevertheless, additional research is needed to determine if these remedies can allow patients to return to using CLs or if they can prevent CL dropout from happening in the first place.

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