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REVIEW

Contact lens wear and dry eyes: challenges and solutions

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Abstract: The number of contact lens wearers worldwide has remained relatively stable over the past decade, despite the investment that has gone into contact lens technology. This is largely because 10%–50% of wearers dropout of contact lens wear within 3 years of commencement; the most common reason cited being contact lens discomfort (CLD). Of the symptoms reported, sensation of dry eye is the most common. Given the outcome of reduced wearing time, increased chair time, and ultimate contact lens discontinuation, the challenge is to identify the warning signs of CLD early on. Clinically detectable changes such as conjunctival staining, conjunctival indentation, conjunctival epithelial flap formation, lid wiper epitheliopathy, *Demodex* blepharitis, and meibomian gland dysfunction have been linked to CLD, highlighting the need to perform regular aftercare visits to identify these changes. At a cellular level, conjunctival metaplasia and reduced goblet cell density have been linked to CLD, leading to a downstream effect on the tear film breakup time of contact lens wearers. These factors suggest a strong link between CLD and friction, raising the need to target this as a means of minimizing CLD. The purpose of this review is to identify the clinical signs that relate to CLD as a means of earlier detection and management in order to combat contact lens dropout.

Keywords: contact lens discomfort, dry eye disease, lid wiper epitheliopathy, tear film biomarkers, meibomian gland dysfunction

Contact lens wear and dry eye: the challenge

An estimated 140 million people worldwide wear contact lenses as a means of refractive error correction,[1] a number that has been remained relatively stable over the past decade, despite the investment that has gone into the improvement of contact lens technology. This is largely because 10%–50% of wearers dropout of contact lens wear within 3 years of commencement, the most common reason cited being contact lens discomfort (CLD),[2] with 70% of people reporting CLD late in the day.[3] Of the symptoms reported, the sensation of dry eye is the most common,[4] with ~40% of soft contact lens wearers reporting this and 25% suffering from moderate to severe symptoms,[5,6] leading to decreased wearing times.[7]

In order to propel the industry forward and address this issue, the Tear Film and Ocular Surface Society (TFOS) commissioned a CLD workshop, which defined CLD as being "a condition characterised by episodic or persistent adverse ocular sensations related to lens wear" and this resulted from "reduced compatibility between the contact lens and the ocular environment".[8] Given the outcome of reduced wearing time, increased chair time, and ultimate contact lens discontinuation, the challenge is to

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identify the "warning signs" of CLD early on. It is therefore important to understand the physiological factors that contribute to the development of CLD if this is to be detected in the early stages and prevented from progressing to the point where wearers feel that they have no alternative but to discontinue contact lens wear. The purpose of this review is to identify the clinical signs relating to CLD as a means of earlier detection, as well as to discuss strategies by which to manage CLD and combat contact lens dropout.

The clinical signs of CLD

The 2013 TFOS CLD workshop categorized CLD into two main categories: that related to the environment and that related to the contact lens.[9] The following section will review the interactions of the lens with the ocular surface, adnexa, and tear film that contribute to contact lens-related dry eye. Given that ~90% of the world's contact lens wearers are wearing soft contact lenses,[10] this report concerns itself with the role of this specific lens category. In keeping with the definition of the 2013 TFOS CLD workshop,[8] CLD rather than "contact lens dry eye" will be used throughout the review.

The ocular surface

The conjunctiva

Contact lenses completely cover the cornea and extend by ~2 mm onto the bulbar conjunctiva, with any well-fitting contact lens moving along the conjunctiva with every blink. This repeated interaction has been found to result in conjunctival changes visible at both a cellular level and at a clinical level and, importantly, is associated with CLD,[11] emphasizing the role that friction may play in propagating CLD.

The bulbar conjunctiva is critical to the maintenance of tear film integrity and mucin production. Mucin is manufactured by the goblet cells scattered along the conjunctival epithelium and it is this mucous product that forms the innermost layer of the tear film. The integrity of the tear film is dependent on the adherence of mucin to the corneal microvilli.[12] Anything that impacts on the health of the goblet cells may therefore impact on the stability of the tear film and result in dry eye symptoms. At the cellular level, contact lens wear has been shown to result in conjunctival metaplasia where the epithelial cells flatten and increase in shape,[13] indicating mechanical friction. Goblet cell density has been reported to decrease following both a 3-month period[14] and a 6-month period of contact lens wear,[15] with this being worse in symptomatic wearers but reversible following lens wear cessation.[16] Interestingly, orthokeratology has been found to improve comfort and increase goblet cell density after 1 month of cessation of silicone hydrogel wear, suggesting that orthokeratology could be regarded as an alternative for those experiencing CLD.[17,18] An increase in Langerhans cell density has also been reported in CLD, suggesting an inflammatory component to the reported discomfort.[19] In reviewing these findings, however, it is important to be mindful of the validity of the techniques used to collect samples. Many studies use impression cytology,[20–25] whereby filter paper is placed onto the bulbar conjunctiva and then removed swiftly, removing with it several layers of conjunctival cells. There is still some need to validate the methodology used when collecting impression cytology samples, with a recent study demonstrating that the distribution of goblet cells across a filter may be highly variable.[18]

At the clinical level, the presence of the contact lens interferes with the thin tear layer so that direct contact with the ocular surface, and hence the conjunctiva, is inevitable, as evidenced by conjunctival staining, conjunctival indentation, conjunctival epithelial flaps,[26–31] and conjunctivochalasis.[32] There are some evidences linking conjunctival staining[33,34] and lid parallel conjunctival folds with CLD,[35] further adding to the hypothesis that friction is a factor contributing to CLD. The impact of contact lens wear on the conjunctiva, and this relationship with CLD suggest that monitoring for conjunctival staining and folds at aftercare visits may assist in the detection of those likely to develop CLD, while managing friction may prevent possible dropout.

The corneal glycocalyx

The role of friction in CLD is further reinforced by the impact of contact lens wear on the corneal glycocalyx.[36] The corneal glycocalyx is a hydrophilic barrier formed by mucins secreted by the epithelial cells.[37] It plays a significant role in minimizing friction between blinks and in stabilizing the tear film on the ocular surface.[37] To further explore this, Fukui et al developed a lectin conjugate of fluorescein as a marker of the corneal glycocalyx. Tear breakup time (TBUT) and fluorescence intensity correlated, indicating that a healthy corneal glycocalyx plays an important role in tear film stability and corneal wettability.[36] When a group of non-lens wearers was first observed over a 10-day period, there was no significant change in fluorescence intensity, indicating no change to the corneal glycocalyx over this period. To explore the impact of contact lens wear on the corneal glycocalyx, a group of soft contact lens wearers was taken out of their lenses for 2 weeks. When contact lens wear recommenced, a clear decrease in fluorescence intensity resulted, and, when contact lens wear ceased, this fluorescence intensity returned

to baseline levels. These findings indicate a reduction in epithelial mucus with contact lens wear with recovery following contact wear cessation, suggesting that the corneal glycocalyx is compromised by contact lens wear[36] and that this may subsequently impact on tear film breakup time and hence comfort. Finding ways to increase the lubrication between the ocular surface and the contact lens may protect the glycocalyx and prevent subsequent tear film instability.

The adnexa

Lid wiper epitheliopathy

The lid wiper has been described as the "portion of the upper eyelid marginal conjunctiva that wipes the ocular, or contact lens surface, during blinking".[38] Lid wiper epitheliopathy is observed through the vital staining of upper and lower lid margins and has been found to be present in 85% of contact lens wearers,[39] with reports linking it to CLD.[11,38] Although the exact etiology of lid wiper epitheliopathy is not understood, it is hypothesized that it results in the absence of adequate lubrication from the tear film and corneal glycocalyx, once again being a result of friction. Varikooty et al have identified five patterns of lid wiper staining:[40] vertical streaks, short horizontal band, speckled appearance, comb appearance, and broad horizontal band. The significance of each of these patterns and how they relate to CLD is not known; however, the very presence of lid wiper epitheliopathy has been suggested to be a useful clinical sign for differentiating clinical performance. Nichols et al assessed lid wiper epitheliopathy as well as CLD in a group of adapted contact lens wearers after randomizing them to rewetting drops containing either carboxymethylcellulose and hyaluronic acid (CMC-HA) or just CMC.[41] The group taking CMC-HA had improved comfort as well as improved lid wiper epitheliopathy staining, supporting its use as a marker of CLD.[41] In support of this, Deng et al analyzed the microvascular network of the lid wiper relative to CLD.[42] The microvascular responses of the lid wiper were significantly correlated with CLD, suggesting that friction may be related to both this hyperemic response and lid wiper staining.[42] Alzahrani et al found an upregulation in Langerhans cells in the lid wiper region in CLD, suggesting an inflammatory component in the etiology of this condition,[43] possibly as a result from the sheer stress of the mechanical interaction between the eyelid and the ocular surface or the contact lens.[44]

Meibomian gland dysfunction (MGD)

The prevalence of dry eye disease ranges between 3.9% and 21.8% across various parts of the world,[45–49] with this being reported to be higher in females than in males[48,49] and higher in the elderly than in the young.[50] One of the challenges of dry eye disease diagnosis is the lack of correlation between the signs and symptoms.[51] This is supported by the knowledge that ~22% of people have MGD, the largest factor contributing to evaporative dry eye disease, without being aware of this.[52] The coexistence of dry eye disease poses a serious challenge in the presence of contact lens wear.

MGD is the most common cause of evaporative dry eye disease.[53] Given that dryness is one of the major factors contributing to contact lens dropout,[54] managing MGD is an important part of managing the challenge of CLD. The contribution that contact lens wear plays in the development of MGD is debated in the literature, with some reports indicating that contact lens wear results in poorer expressibility of the meibomian glands,[55] whereas a more recent report indicated that contact lens wear contributes to meibomian gland dropout.[56] These findings are supported by a study by Alghamdi et al, indicating that the first 2 years of contact lens wear result in both gland dropout and gland orifice obstruction, stabilizing after this point.[57] This is in contrast to reports that state there is no increased risk of MGD with contact lens wear.[58] Although contact lens wear may contribute to the development of MGD, MGD may cause CLD. Cox et al examined the eyelid features that contribute to CLD and identified displacement of the mucocutaneous junction and meibomian gland expressibility as having a significant effect.[59] Given the evidence available, identifying and managing MGD prior to and during contact lens wear, particularly over the first few years,[57] seen to be a critical means by which to manage CLD. The meibomian glands need to be carefully assessed for expressibility, surface obstruction, and morphology and MGD needs to be treated proactively in contact lens wearers.

Demodex blepharitis

As with MGD, eyelash infestation with the ectoparasite *Demodex* is a condition frequently encountered in clinical practice and is typically diagnosed by observing depilated eyelashes under the light microscope[60] or by using in vivo confocal microscopy.[60] Although there are many species of *Demodex*, only two are present on the ocular surface: *Demodex folliculorum* that lives in the lash follicles and *Demodex brevis* that resides in the sebaceous and meibomian glands.[61] In patients aged >70 years, the presence of *Demodex* on the lashes reaches a prevalence of 100%.[61] The relationship between CLD and *Demodex* has been explored by epilating the lashes of both tolerant and intolerant contact lens wearers and observing these under the light microscope.[62]

Interestingly, 94% of the intolerant lens wearers had *Demodex*, whereas only 6% of the tolerant contact lens wearers exhibited this condition.[62] Hom et al recommend a clinical sequence to diagnose, and hence manage, those with *Demodex*.[63] This includes a clinical history of blepharitis and dry eyes, slit lamp examination including the assessment for the presence of cylindrical dandruff at the eyelashes and confirmation using light microscope evaluation of epilated lashes.[63]

The tear film

Tear film breakup time

During contact lens wear, the lens interacts with the tear film, separating this into the pre- and post-lens tear film. This affects the tear film lipid layer spread, tear film stability, and tear evaporation, which in turn contributes to CLD.[64] A reduction in tear film stability and impaired lipid layer function result in less lubrication and greater friction between the contact lens and the ocular surface, propagating the cycle of CLD. The 2013 TFOS CLD report considered the biophysical and biochemical aspects of the tear film and highlighted that a low TBUT was associated with CLD, as was tear ferning.[64]

TBUT, when measured both non-invasively and with fluorescein, has been found to differentiate successful contact lens wearers from those that dropout of contact lens wear, with wettability being the main factor affecting contact lens dropout.[65] This is supported by the findings of Guillon et al[66] who examined the pre-lens tear film kinetics in symptomatic and asymptomatic contact lens wearers. Symptomatic contact lens wearers were distinguished by a low TBUT, less tear film coverage during the inter-blink period, and greater surface exposure at the time of the blink.[66] Identifying contact lens wearers with low TBUTs and managing their tear quality early on may be key to preventing contact lens dropout.

Tear film biomarkers of CLD

Efron argues in a recent paper that "normal, asymptomatic contact lens wear is intrinsically inflammatory"[67] and states that this places the ocular surface in a state of "heightened alert", hence being a protective mechanism. Although this may be the case, it is important to note that there is no reference to inflammation in the definition of CLD,[8] and, overall, the changes in the cardinal signs of inflammation (robor – redness, calor – heat, tumor – swelling, dolor – pain, and function laesa – loss of function)[68] during contact lens wear are slight and have not been found to correlate with CLD.[11] In contrast, the role of inflammation in dry eye disease is well accepted.[69] However, there may be more subtle markers of inflammation in the tear film that are related to CLD. With respect to biochemical changes in tear film, the 2013 TFOS CLD report found that levels of tear lipocalin-1 and phospholipids were associated with CLD, but the relationship between mucins and CLD was inconclusive.[64] Since then, Lopez-de la Rosa et al found no difference in 11 cytokines between symptomatic and asymptomatic contact lens wearers,[70] whereas Willcox et al found a correlation only between vascular endothelial growth factor (VEGF) and comfort – and even then, the change in VEGF was more pronounced when contact lenses were not worn.[71] Leukotriene B4 has been found to increase during contact lens wear and with CLD,[72] whereas a negative association has been reported with prolactin-induced protein.[73] Matrix metalloproteinase-9, a collagen-degrading enzyme and a marker of dry eye disease,[74] has been found to increase in concentration with extended wear of contact lenses,[75] but no association has been explored with regard to CLD. No association has been found between CLD and the complement system and histamine,[72] although the role of other allergic markers or neuropeptides has not been explored. The collective evidence indicates that, although contact lens wear may induce a low-key inflammatory response, this does not appear to be the underlying cause of CLD.

Contact lens wear duration

In order to establish whether CLD is a function of the time of day at which lenses are worn, Papas et al assessed comfort in a group of participants without lens wear over an 8-h period and showed that this stayed reasonably constant throughout the observation period.[76] When participants were fitted with contact lenses for 12 h, after the first few hours, comfort scores reduced significantly, in a fashion typical of that commonly expressed by contact lens wearers. When participants were asked to wear the contact lenses for 4-h periods starting in the morning, in the afternoon, or late afternoon, a characteristic pattern resulted, regardless of the starting point. Scores increased slightly between insertion and 2 h and then declined by the 4-h point. These findings indicate that short bursts of comfortable contact lens wear can be experienced at any time of the day without a significant change in comfort. The corollary to this is that something changes after the 4-h mark and that needs to be understood in order to combat CLD.

Lens age and replacement frequency

Lens age and replacement frequency were reviewed in a retrospective chart review at a single contact lens practice from extended wear patients, where 65 wore disposable contact lenses and 61 wore conventional lenses.[77] Symptoms of CLD were reduced in the disposable group indicating that

increasing lens age is a factor in producing such symptoms. When daily wear was considered, Solomon et al also found an improvement with a daily versus a 2-week replacement schedule with increasing replacement frequency leading to better comfort and patient satisfaction.[78]

Managing CLD

In order to identify CLD, Papas et al recommend regular aftercare visits, establishing the current status of the contact lens and its interactions with the ocular surface and adnexa,[79] including vital staining of the cornea, conjunctiva, lid wiper, and tear film. In addition, there is a need to identify risk factors such as the coexistence of allergy, for example, which can further induce or exacerbate the symptoms of CLD leading to discontinuation of contact lens wear.[80,81]

Minimizing friction

Given the association between CLD and clinical signs such as conjunctival staining, TBUT, lid wiper epitheliopathy, and MGD, the role of friction cannot be overlooked. Every aspect of CLD management should therefore take into account means by which to increase lubrication between the contact lens and the ocular surface and adnexa. The treatment efficacy of lubricating eye drops in relieving CLD has been studied extensively,[82–85] and the advent of preservative free lubricant eye drops has been shown to improve CLD.[86–88] In a further attempt to minimize friction, Guthrie et al used an oil-in-water emulsion in symptomatic contact lens wearers and were able to show that this improved CLD and reduced lid wiper staining.[88] In another approach, lubricin, which acts to protect cartilage tissue against friction-related damage, has been advocated as a means to reduce friction between the ocular surface and the eyelids.[89] Schmidt et al identified the expression of lubricin by the ocular surface and reported that its absence may be indicative of sheer stress and friction-related damage.[89] In a study comparing the efficacy of lubricin and sodium hyaluronate in the treatment of dry eye symptoms, a significant improvement in symptoms, TBUT, and corneal staining was found with lubricin.[90] These findings are promising for dry eye disease management and may also play a role in the management of CLD in the future.

Managing MGD

Intertwined with CLD management and minimization of friction should also be a strict regimen to manage the coexistence of dry eye disease and MGD. Although traditional warm compresses can be effective in restoring the function of the meibomian glands,[91] patient compliance can be challenging. Recently, microwavable eye masks that use silica bead technology to increase moisture while simultaneously applying heat over the blocked orifices have been developed.[92,93] Such eye masks are thought to be more effective than traditional warm compresses in maintaining a constant temperature and hence restoring the normal function of the meibomian glands.[94,95] In-office eyelid warming devices such as Blephasteam® (Laboratoires Thea, Clermont-Ferrand, France) have also been reported to restore the function of the meibomian glands and decrease the symptoms of dry eyes.[96] Blephasteam uses moisture rings to produce steam and warmth inside the instrument that can open the blocked Meibomian gland orifices when used for a period of 10 min.[97–99] Another in-office eyelid thermal pulsation treatment known as the LipiFlow (Tearscience®, Morrisville, NC, USA) that applies heat to the palpebral surfaces of the eyelids while simultaneously applying pressure on the eyelids to express the meibomian glands had been developed.[100] A 12-min LipiFlow session administered in-office was found to be more effective in treating MGD than conventional warm compresses and lid hygiene.[101,102]

Changing contact lens material and replacement schedule

Papas et al recommend changing the contact lens type or the wear schedule to minimize CLD.[79] To this end, new water gradient daily disposable contact lenses have been developed with the promise of improving comfort. In this design of daily disposable soft contact lens, the core water content of the lens is maintained at 33%, and the surface water content of the lens is maintained at 80% allowing the lens material to have low modulus, with high wettability and high lubricity. Comfort during the first 12 h of lens wear as well as end of day comfort has been found to be superior in the water gradient daily disposable silicone hydrogel lenses compared to conventional daily disposable silicone hydrogel lenses.[103] A recent study has shown that after 6 h of lens wear, these lenses resulted in a much lower disruption of the pre-corneal tear film quality compared to regular silicone hydrogel lenses.[104]

Future directions

While the future may see the contact lens industry incorporating lubricin or other measures to reduce friction between the ocular surface and the contact lens, current evidence-based measures need to be implemented to overcome CLD. Importantly, each patient needs to be reviewed for the risk factors of CLD, with these being addressed as early as possible in order to minimize the number of people resorting to contact lens discontinuation.

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