Tear Menisci and Ocular Discomfort during Daily Contact Lens Wear in Symptomatic Wearers

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PURPOSE. To investigate the relationship between tear meniscus volumes and ocular discomfort during daily soft contact lens wear in symptomatic and asymptomatic wearers.

METHODS. Three groups of subjects (n = 20 each) were enrolled. Group 1: symptomatic lens wearers; group 2: asymptomatic lens wearers; group 3: asymptomatic non-lens wearers. Lenses were worn on both eyes and imaged at 2, 4, 6, 8, and 10 hours by optical coherence tomography (OCT). Afterward, a re-wetting drop was instilled onto a randomly selected eye of each subject and re-imaged immediately and at 5, 10, 20, and 30 minutes. Tear meniscus volumes were calculated based on meniscus areas and eyelid lengths. Ocular comfort was also ranked at each time point.

RESULTS. Upper and lower meniscus volumes in group 1 were the lowest among the three groups at each time point (P < 0.05). For each group, meniscus volumes decreased gradually during the 10-hour study period (P < 0.05). Among the individuals in each group, the comfort ratings were linearly correlated with the tear meniscus volumes during the 10 hours of lens wear (r = 0.21-0.47, all P < 0.05). Tear volume increased after re-wetting, but lasted only 10-20 minutes. Ocular comfort in groups 1 and 2 increased after instillation, but lasted only 10-20 minutes, respectively. Ocular comfort in group 3 did not improve.

CONCLUSIONS. Tear volume decreased gradually during lens wear and contributed to the ocular comfort in both symptomatic and asymptomatic wearers. The efficacy of re-wetting was brief. (Invest Ophthalmol Vis Sci. 2011;52:2175–2180) DOI: 10.1167/iovs.10-5780

A large percentage of soft contact lens wearers discontinue use because of contact lens-associated dryness and discomfort.1–3 The stability,4–6 volume,4,5,7 composition,6 osmolarity of tears,8 and appearance of ocular surface9,10 in lens-induced dry eyes are all different from those in asymptomatic wearers and those who do not wear lenses. Among those changes, decreased tear volume may be a major factor that induces contact lens symptoms and intolerance.4 Many contact lens wearers often complain of ocular dryness and discomfort, especially after wearing them all day.11,12 This may indicate that tear volume decreases gradually during daily contact lens wear. However, there is little information regarding such changes during long-term wear, possibly because of the limitation of reliable methods for dynamically evaluating tear volume. Approximately 75%–90% of the tear volume exists in upper and lower tear menisci.13 The measurement of tear meniscus dimensions therefore may be a good indicator for the total tear volume. Real-time anterior segment optical coherence tomography (OCT) is a useful and promising tool for quantifying tear menisci, both with and without contact lens wear.14–16 The goals of this study were to investigate variation of the tear menisci during daily soft contact lens wear and establish the relationship between ocular comfort and tear meniscus volumes in symptomatic and asymptomatic populations.

SUBJECTS AND METHODS

The present study was approved by the research review board of Wenzhou Medical College and informed consent was obtained from each subject. Each subject was treated in accordance with the tenets of the Declaration of Helsinki. All participants were screened by a survey of general and ophthalmic medical history and slit-lamp microscopy, tear breakup time (TBUT), modified Schirmer I test, and an eight-question dry eye questionnaire.17 The dioptic prescription for each subject who wore contact lenses was obtained. Three groups of 20 subjects were recruited and grouped according to their history of soft contact lens wear and self-reported dry eye. Any subject who responded to the dry eye questionnaire by identifying at least one symptom occurring often or continually was considered to be symptomatic.17 TBUT and Schirmer I test were not used to assign subjects to the different groups. The subjects in group 1 (16 women and 4 men, mean ± SD; age: 25.3 ± 1.5 years) had self-reported dry eye symptoms often or continuously with 3 months to 10 years of soft contact lens wearing experience. Group 2 subjects (16 women and 4 men; age: 25.4 ± 2.5 years) were successfully adapted soft contact lens wearers with lens wearing history from 1 month to 7 years and no dry eye related complaints. Group 3 subjects (12 women and 8 men; age: 21.4 ± 2.1 years) had never worn contact lenses. Subjects in group 2 and group 3 had no history of previously diagnosed dry eye, and none of the subjects in the three groups had any other current ocular or systemic diseases.

We provided each subject with the same type of refractive error-specific hydrogel contact lenses (Acuvue 1-Day [etafilcon A, 58% water content; base curve, 8.5 mm; diameter, 14.20 mm]; Vistakon, Johnson & Johnson, Jacksonville, FL). There were no significant differences in contact lens power among the three groups (ANOVA, P > 0.05). The contact lenses were inserted onto both eyes of each subject at 8:00 AM and worn for 10 hours. OCT imaging was conducted at every two hours during lens wear (Figs. 1A–E). After imaging, one drop (20 μL) of re-wetting drops (ReNu MultiPlus; Bausch & Lomb, Rochester NY) was instilled into one randomly selected eye of each subject, and the
other eye was treated as the control. OCT imaging was again conducted on both eyes immediately and at 5, 10, 20, 30 minutes after instillation (Fig. 1F–J). The ocular comfort level was determined by a questionnaire that used a continuous analog scale from 0 to 50, similar to the one others have used. Lower ratings reflected poor comfort of dry or gritty eyes, while higher values reflected good comfort and little to no symptoms. As described in previous studies,15,19 the whole procedure was conducted in a consulting room in which the temperature and humidity were controlled within 15° to 25°C and 30% to 50%, respectively.

Images of the total cornea with contact lens and both menisci were taken using a real-time, custom-built, time domain OCT instrument designed for the anterior segment.15,16 The OCT light source was 1310 nm with a bandwidth of 60 nm. Up to a 15-mm scan width could be achieved by the telecentric light delivery system. The OCT axial resolution in tissue is approximately 10 μm. The upper and lower tear menisci between the eyelid and contact lens were imaged simultaneously with scans of 8 frames per second, 12.5-mm width, and 2-mm depth. The vertical scan was centered across the apex of cornea and contact lens. A digital video viewer that incorporated the OCT scan light across the center vertically. The ambient light in the research room was dimmed enough to avoid reflex tearing. A digital camera on another slit-lamp was used to take pictures of each eye to measure eyelid length for the calculation of the tear meniscus volumes.

During each OCT session, the subjects were asked to look at an external central target and blink normally. Images were captured immediately after these blinks. The first good post-blink image showing both upper and lower tear menisci and a specular reflex across the central apex of contact lens was adopted. Custom software, as described previously,14–16 was used for processing the OCT images to obtain the cross-sectional areas of the upper and lower tear menisci on the soft contact lens. This information, along with the corrected eyelid lengths17 obtained from the digital photographs, was used to calculate the upper and lower tear meniscus volumes (UTMV and LTMV). The total tear meniscus volume (TTMV) was the sum of UTMV and LTMV.

Values were presented as means ± standard deviations for all three groups at all the time points. Data analysis was conducted with a package of statistical analysis software (Statistica; StatSoft, Tulsa, OK). Paired t-tests were used to determine whether there were any differences between right and left eyes. Repeated analysis of variance (Re-ANOVA) was used to test significant differences between the measured variables over time. Post hoc tests were used to determine significance differences in pairs of values. Pearson correlation was used to test correlations between the ocular comfort and the tear meniscus volumes.

**RESULTS**

There were no significant differences of UTMV, LTMV, TTMV, or subjective ocular comfort ratings between left and right eyes of any of the subjects over the five time points of the 10 hour study period (paired t-tests, P > 0.05). Therefore, tear meniscus volumes and the comfort ratings of left and right eyes were averaged for each individual.

During the 10 hours of contact lens wear, the comfort ratings in group 1, the experienced symptomatic wearers, did not decrease until six hours. However, for group 2, the experienced asymptomatic wearers, and group 3, the inexperienced wearers, the comfort ratings decreased at 10 hours of wear (post hoc tests, P < 0.05, Fig. 2A). For all three groups, none of the tear menisci volumes were significantly decreased at four hours of wear compared to two hours (P > 0.05; Figs. 1, 2B, 2C, 2D). However by six hours, each of the volumes in the three groups was lower than that at two hours (P < 0.05).

The UTMV and TTMV in group 1, the LTMV and TTMV in group 2, and the TTMV in group 3 decreased further after eight hours.
hours of lens wear ($P < 0.05$, compared with six hours). By 10 hours of lens wear, LTMV in group 1, UTMV in group 2, and the UTMV and LTMV in group 3 had all decreased ($P < 0.05$, compared with eight hours). The UTMV, LTMV, and TTMV in group 1 were the lowest among the three groups at each time point ($P < 0.05$; Figs. 2B, 2C, 2D). The UTMV in group 3 was the highest ($P < 0.05$) at each time point, while the LTMV and TTMV in group 3 were not different from those in group 2 ($P > 0.05$). For group 2, the experienced asymptomatic wearers, the volumes at eight and 10 hours were similar to those of group 1 at six hours. For group 3, the inexperienced wearers, the volumes at 10 hours were similar to those of group 1 at six hours. Among the individuals in each group, all the comfort ratings assessed throughout the 10 hours of lens wear were linearly correlated with the simultaneous tear meniscus volumes (Pearson correlation, $r = 0.21$–$0.47$, all $P < 0.05$; Fig. 3).

After 10 hours of lens wear, one drop was instilled on a randomly chosen eye for each subject. The ocular comfort ratings of the treated eye in group 1 and group 2 improved significantly immediately after instillation (post hoc tests, $P < 0.05$; Fig. 4A). The improvement in group 1 and group 2 lasted for 10 minutes and 20 minutes, respectively ($P > 0.05$). However, in group 3, the ocular comfort ratings did not change after instillation ($P > 0.05$). For the control eyes in all three groups, the comfort ratings were not affected by the instillation on the treated eyes ($P > 0.05$, Fig. 4A). The tear meniscus volumes increased significantly immediately after instillation ($P < 0.05$; Figs. 1F, 4B, 4C, 4D). Except for UTMV in group 3, which was restored to the pre-instillation volume at 10 minutes, all the variables returned to pre-instillation values 20 minutes after instillation ($P > 0.05$). The volumes of the contralateral control eyes in each group were not affected by instillation of drops onto the treated eyes ($P > 0.05$; Figs. 4B, 4C, 4D). Except for immediately after instillation, the tear volumes for the group 1 eyes were the lowest at each time point after instillation ($P < 0.05$), and the volumes in group 3 eyes were the highest ($P < 0.05$).

**DISCUSSION**

In the present study, we monitored the tear meniscus volumes and the ocular comfort ratings for long-term daily contact lens wear. At two hours of lens wear, the tear meniscus volumes for all three groups were lower than those that we reported at 30 minutes in a previous study on a similar population of subjects. In contrast, Wang et al. found that the tear menisci did not change even after four hours of lens wear compared to the baseline and 20 minutes. They suggested that a dynamic balance was reached at four hours after a short period of lens adaptation. The reason for the difference in our results and theirs may be that the contact lenses used in these two studies were not the same. Wang et al. used balafilcon A lenses with base curve of 8.6 mm and galafilm A lenses with base curve 8.3 of mm. The diameter of both lenses was 14 mm. The different materials in these studies may have impacted the time of adaptation. In addition, the dry eye tests for screening and selecting normal subjects give highly variable results. Thus it is possible that among the normal subjects in both studies, there were some who bordered on having early indications of incipient dry eyes. Another difference is that duration of the earlier studies was only 30 minutes or 4 hours. In the study reported here, tear volumes continually decreased after four hours, compared to 30 minutes as reported in our previous study.

For longer periods of wear, tear evaporation may contribute to the reduced volumes and increased tear osmolarity. This might reasonably explain the complaints about dryness and discomfort late in the day that is common for both symptomatic and asymptomatic wearers. However, Glasson et al. reported that six hours of contact lens wear increased the tear meniscus area in tolerant wearers while having no effect on meniscus area in intolerant wearers. This finding was not in agreement with ours. Glasson et al. suspected that the increase of the tear meniscus area (not the tear meniscus height) may be due to the “slight irritation” when the lens was on the eye. They also suggested that the increase may be

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**FIGURE 2.** Ocular comfort ratings (A) and UTMV (B), LTMV (C) and TTMV (D) during 10 hours of contact lens wear. Group 1: experienced contact lens wearers with dry eye complaints; group 2: experienced contact lens wearers without dry eye complaints; group 3: inexperienced contact lens wearers without dry eye complaints.
due to the movement of the lower lid which caused the changes of the tear meniscus area. Comparing their results of the tear meniscus to our results, it may be also possible that the increase in their study may be induced by reflex tearing due to the illumination and the presence of the lens. They measured only the lower meniscus area by slit-lamp biomicroscopy. It is likely that the inability to simultaneously measure both menisci, the limitations of the accuracy, and the inability to identify with certainty the upper extremity of the tear meniscus could also explain their results.23

In the present study, the symptomatic wearers in group 1 reported early onset of ocular discomfort. This was compatible...
with the finding that the tear volumes in this group were the lowest, which likely contributed to their complaints of dryness and discomfort. Furthermore, for all three groups, ocular discomfort appeared when the TTMV decreased to a similar level. In addition, there were strong correlations between the tear meniscus volumes and ocular comfort in all three groups. These results indicate that the reduction of tear volume may be one of the main reasons for ocular discomfort and dryness that occurs after a long period of lens wear, as suggested by Mainstone et al. They found a correlation between the volume and dryness sensation in non-lens wearing dry eye patients. The balance of tear dynamics in group 2, the asymptomatic experienced wearers, was not affected during contact lens wear as the LTMV and TTMV were similar to those in the normal inexperienced lens wearers during the 10 hour study period. Other reasons like contact lens dehydration, presence of deposits between the contact lens and the cornea, and increase of osmolarity might also contribute to these symptoms appearing late in the day during lens wear.

Indubitably, the use of lubricating drops improved the ocular comfort of both experienced symptomatic and asymptomatic wearers, even though the improvement lasted for only several minutes. For all three groups, the drop increased the tear meniscus volumes for approximately 20 minutes. These results indicated that the efficacy of the lubricating drop was short-term, as suggested by Wang et al. We speculate that lens re-hydration, rinsing off of lens deposits, and decreased osmolarity after using lubricating drops might be the reasons for the improvement in ocular comfort. In addition, in our previous study, we reported that the instilled drops do not flow around the lens edge to increase the post-lens tear film. This indicated the lubricating drops did not improve the ocular comfort by increasing the post-lens tear film. However, the increase of the pre-lens tear film after using drops might increase ocular comfort by relieving the friction between the eyelid and contact lens surface.

When we instilled one drop onto a randomly selected eye, neither the ocular comfort nor the tear volume of the contralateral untreated eye changed for any of the subjects in the three groups. The activation of the sensory nerves in the cornea induces reflex tearing that often occurs in the contralateral eye. However, the transient increase of tear volume and improved ocular comfort of the instilled eye had no reflexive effect on the contralateral control eye. Thus, the comfort of the contralateral eye did not improve, as the tear volume was not increased. Our study was restricted to lenses composed of etafilcon A with a water content of 58%. Other lens types (e.g., silicone hydrogel lenses and RGP lenses) may elicit a different profile of dynamic tear changes. These and the effect of overnight lens wear will be the subjects of future studies.

In this study, we strictly controlled the temperature and humidity in 15–25°C and 30%–50%, respectively. Environmental conditions especially the humidity will change the evaporation of the tear film. Maruyama et al. suggested that the change of environmental conditions was considered to mainly affect the stability of tear film, but not the tear meniscus. They found that the tear meniscus radius with and without contact lens in different environmental conditions with a certain range of controlling temperature (5–35°C) and humidity (10%–50%) were not significantly different. This indicated that the changes of environmental conditions in such ranges of temperature and humidity would not affect the tear meniscus volume. The temperature and humidity of the controlled room in our study were within the ranges reported by Maruyama et al., although the contact lenses tested were not the same.

In summary, we used a custom-built, real-time OCT instrument to detect the dynamic changes in the upper and lower tear menisci during long-term contact lens wear. Low tear volume in lens wearers with dry eye symptoms contributed to the complaint of dryness. There was a gradual decrease of tear volume during the 10 hours of lens wear that correlated with the onset of dryness symptoms in both symptomatic and asymptomatic wearers. Lubricating drops delivered to one eye improved the ocular comfort for that eye; however, the efficacy was short-term and did not extend to the tear volume or ocular comfort of the untreated contralateral eye.

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