Lower Volumes of Tear Menisci in Contact Lens Wearers with Dry Eye Symptoms

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PURPOSE. To investigate tear meniscus volumes during short-term lens wear by soft contact lens (SCL) wearers with dryness symptoms.

METHODS. Three groups of 20 subjects were recruited. Group 1 consisted of SCL wearers with self-reported dryness. Group 2 consisted of asymptomatic wearers. Group 3 was composed of asymptomatic non–lens wearers. Contact lenses were fitted on each eye, and both upper and lower tear menisci were imaged before lens insertion, immediately after insertion, and 30 minutes later, using optical coherence tomography. Custom software was used to yield the tear meniscus area, and then the volumes were calculated based on eyelid length. Repeatability was tested 30 minutes after lens wear on two consecutive days.

RESULTS. There were no significant differences (P > 0.05) between the volumes measured at 30 minutes after lens insertion on 2 days. In addition, the repeatability between days was similar among the groups. The upper and lower meniscus volumes were significantly lower in group 1 than in either of the asymptomatic groups at baseline, immediately after insertion, and 30 minutes later (P < 0.05). The upper tear meniscus in group 3 was greater than in group 2 at all times (P < 0.05). The lower meniscus volume immediately after insertion was significantly higher in group 3, the inexperienced wearers, than in group 2 (P < 0.05); however, the volumes at baseline and 30 minutes later were similar to one another (P > 0.05).

CONCLUSIONS. Tear volumes in dry eye symptomatic wearers were lower than asymptomatic wearers at baseline and during lens wear, which may have contributed to the dryness. (Invest Ophthal Vis Sci. 2009;50:3159–3163) DOI:10.1167/iovs.08-2794

Balance in the tear system plays a significant role in maintaining the comfort, health, and optical quality of the eye. Wearing contact lenses is one of many internal and external factors that can disturb tear dynamics, potentially resulting in ocular discomfort, dryness, and diseases.1–4 According to the dry eye diagnostic classification scheme from the National Eye Institute and Industry Workshop, the etiology of contact lens–associated dry eye is evaporative loss of tears.5–6 More than half of contact lens wearers self-report dry eye symptoms.1 Some of these wearers reduce their lens-wear time and some eventually abandon lens wear. Over 15% of abandoned lens wear is due to dryness, and nearly 30% is due to ocular discomfort.7

Many studies have focused on the mechanisms,6,8–11 diagnosis,1,5,12 management,3,5 and precautionary measures2,13 of contact lens–related dry eye. Evaluation of the tear meniscus has been used to determine the effects of different types of lenses14 and of environmental conditions on contact lens wearers.4 Clearly, the tear system is altered when the lens is on the eye, regardless of lens type. Because of the extreme difficulty of imaging the tear menisci around both eyelids, not much information is available in the literature regarding the tear meniscus volume on and around the contact lens, especially in wearers with dry eye symptoms. In our previous study, the methodology of using real-time optical coherence tomography (OCT) to measure upper and lower menisci on contact lenses was verified in normal subjects.15 The goal of the present study was to measure tear volumes in tear menisci on contact lenses in wearers with and without dry eye symptoms.

METHODS

This prospective study was approved by the research review board of Wenzhou Medical College. Informed consent was obtained from each subject, and all were treated in accordance with the tenets of the Declaration of Helsinki. Potential subjects were screened by a survey of general and ophthalmic history, including contact lens wear and artificial tear use, slit lamp biomicroscopy, tear breakup time (TBUT), and the modified Schirmer I test. The results of TBUT and Schirmer I test were not used for grouping, but compared among groups. Sixty participants conforming to the inclusion criteria described below were enrolled and categorized into three groups: Group 1 (16 women and 4 men; mean ± SD age, 23.5 ± 1.5 years) was composed of subjects with 3 months to 10 years of soft contact lens experience and with current self-reported dry eye symptoms. Dryness symptoms were defined as complaints of at least one symptom that occurred often or continuously according to a dry-eye questionnaire that consisted of eight questions.12 Group 2 (16 women and 4 men; mean ± SD age, 23.4 ± 2.5 years) were adapted soft contact lens wearers with 1 month to 7 years of soft contact lens experience and with no complaints of dry eye symptoms. Group 3 (12 women and 8 men; mean ± SD age, 21.4 ± 2.1 years) were asymptomatic subjects who had never worn contact lenses. The subjects in groups 1 and 2 wore contact lenses for at least 10 hours a day and at least 5 days a week. Neither group 2 nor group 3 subjects had any history of previously diagnosed dry eye or any current ocular or systemic diseases. None of the subjects enrolled had ever used artificial tears.

Subjects participated in this study on two consecutive days. On the first day, repeated OCT measurements were conducted 30 minutes after lens insertion. Commercially available hydrogel contact lenses (etafilcon A, 58% water content; Acuvue 1-DAY, Vistakon; Johnson & Johnson, Jacksonville, FL) with refractive-error–specific diopeters were inserted onto both eyes. On the second day, OCT images were taken at baseline before lens insertion, immediately after lens insertion, and 30 minutes after insertion (Fig. 1). The study was conducted in a consulting room in which the temperature (15–25°C) and humidity (30%–50%) were controlled by central air conditioning and a humidifier.
A real-time anterior segment OCT, as previously reported,15–17 was used in the study. In brief, a light source with 1310-nm wavelength and 60-nm bandwidth was mounted on a telecentric light delivery system that enabled a full 15-mm scan width. The scan speed was set to eight frames per second. A vertical scan of 12.5-mm width was made across the central cornea and the apex of the contact lens so that the upper and lower tear menisci between the eyelid and lens were imaged simultaneously. The OCT axial resolution in tissue was approximately 10 μm, and the scan depth was 2 mm in air. A digital video viewer that incorporated the OCT scanning system was mounted on a standard slit lamp and used to locate the scan light across the center vertically. During imaging, the subjects were asked to look at an external central target. The room light was dimmed to avoid reflex tearing. A digital camera on another slit lamp was used to take photos of each eye to obtain the eyelid lengths needed for tear meniscus volume calculations.

To obtain the dimensional information of the upper and lower tear menisci on soft contact lenses, we used custom software for OCT image processing. This software was described previously and used to acquire all the variables of the upper and lower tear menisci with and without contact lens wear.15–17 The first good image taken immediately after blinking that showed both upper and lower tear menisci as well as the central apex of the contact lens was used. To outline the surface of the contact lens, a three-point method was used that included junctions between the contact lens and the upper and lower tear menisci and the central point of the front surface of the lens (Figs. 2A, 2B). Touch points between the eyelids and the upper and lower tear menisci were calculated by the custom software. To obtain tear meniscus volumes, we measured the lengths of the upper and lower eyelids on the two-dimensional digital images of each subject’s eyes. As the eyelids are actually curved in the third dimension, the eyelid lengths in the two-dimensional images were adjusted by a multiplication factor of 1.294 according to Tiffany et al.18 The cross-sectional areas of the tear menisci and the eyelid lengths were used to calculate the upper and lower tear meniscus volumes (UTMV and LTMV), as described previously.19 The total tear meniscus volume (TTMV) was calculated as the sum of UTMV and the LTMV.

**Figure 1.** Tear menisci of the upper and lower eyelids during contact lens wear. The real-time anterior segment OCT images were obtained immediately after a full blink by a subject with dry eye symptoms. A vertical 12.5-mm scan was performed to cross the apex of the cornea and contact lens. The images were obtained at baseline (A), immediately after lens insertion (B), and 30 minutes after insertion (C). The cornea (CO), soft contact lens (asterisk in B), upper tear meniscus (UTM) around the upper eyelid (UL) and lower tear meniscus (LTM) around the lower eyelid (LL) were clearly visualized. The lower tear meniscus at the lens insertion (B) was clearly greater than at baseline (A) or at 30 minutes (C). Bars, 500 μm.

**Figure 2.** Image processing for tear meniscus variables on the contact lens. All the measured variables were obtained from the OCT image (A) with custom software. In image (B), a three-point method was used to fit a curve (green) to outline the contact lens surface. Red dots were placed at the junctions between the contact lens and the upper and lower tear menisci and also at the apex of the front surface of the lens. In images (C) and (D), touch points (green dots) between the upper (C) and lower (D) tear menisci and the respective eyelids, the junctions (pink dots) of the contact lens (green curve) and upper and lower eyelids, and the central points (blue dots) of the front surface of tear menisci were marked. A circle fitted by the red, blue, and green dots was used to yield tear meniscus curvature (red curve). Based on these points and outlines, the cross-sectional areas bounded by the red, yellow, and green lines of the upper and lower tear menisci were calculated.

A real-time anterior segment OCT, as previously reported,15–17 was used in the study. In brief, a light source with 1510-nm wavelength and 60-nm bandwidth was mounted on a telecentric light delivery system
Data were analyzed by statistical analysis software (Statistica; StatSoft, Inc., Tulsa, OK). Paired t-tests were used to determine whether there were any differences between the right and left eyes. Post hoc tests were performed to compare volumes at baseline, immediately after lens insertion, and 30 minutes after lens insertion. The repeatability of real-time OCT tear menisci measurements was defined by the standard deviation of differences of the measured variables between the two days obtained at 30 minutes after lens insertion. \( P < 0.05 \) was considered significant.

**RESULTS**

TBUT in group 1, 4.0 ± 2.0 seconds, was significantly lower than that of the asymptomatic non-contact-lens wearers in group 3, 5.6 ± 3.2 seconds (post hoc tests, \( P < 0.05 \)). The TBUT values in group 2, 5.2 ± 2.8 seconds, was much higher than that in group 1 and was close to that in group 3. However, there were no differences either between groups 1 and 2 (\( P > 0.05 \)) or between groups 2 and 3 (\( P > 0.05 \)). In the symptomatic lens wearers in group 1, the Schirmer I test result (5.3 ± 5.9 mm) was not significantly different from the result in the asymptomatic wearers in group 2 (6.6 ± 5.0 mm; post hoc tests, \( P > 0.05 \)). The Schirmer I test results in both groups 1 and 2 were significantly lower than that in the normal non-lens wearers, 9.8 ± 8.5 mm (post hoc tests, \( P < 0.05 \)).

There were no significant differences between right and left eyes in tear meniscus volumes within any of the three groups (paired t-tests, \( P > 0.05 \)). Right and left eye meniscus volumes were averaged for each individual, and those values were used for all comparisons. Within each group, there were no significant differences in UTMV, LTMV, and TTMV measured at 30 minutes after contact lens insertion on the two consecutive days (paired t-tests, \( P > 0.05 \), Table 1). Repeatability 30 minutes after lens insertion, as measured by the standard deviation of the differences between measurements made on consecutive days, was similar among the three groups (ANOVA, \( P > 0.05 \), Table 1). At baseline, there were significant differences in UTMV and TTMV among the three groups (ANOVA, \( P < 0.05 \), Table 2, Fig. 3), with the lowest in group 1 and the highest in group 3 (post hoc tests, \( P < 0.05 \)). For the LTMV, the baseline value in group 1 was the lowest (post hoc tests, \( P < 0.05 \), Table 2, Fig. 3), whereas the two asymptomatic groups were not significantly different from one another (\( P > 0.05 \)).

Tear meniscus volumes increased immediately after contact lens insertion in all groups (post hoc tests, \( P < 0.005 \) for all comparisons, Table 2, Fig. 3). Immediately after lens insertion, the UTMV and LTMV in group 1 were significantly lower than the comparable volumes of both groups 2 and 3 (\( P < 0.05 \), Table 2, Fig. 3). At the same time, all the measured variables in group 2 were significantly lower than those in group 3 (post hoc tests, \( P < 0.05 \)).

By 30 minutes after lens insertion, each variable in all three groups had recovered and was not significantly different from baseline levels (\( P > 0.05 \), Table 2, Fig. 3). At 30 minutes, each variable was the lowest in group 1, and UTMV and TTMV in group 3 were greater than in the other two groups (\( P < 0.05 \), Table 2, Fig. 3). However, the LTMVs in groups 2 and 3 were not significantly different from one another after 30 minutes of lens wear (post hoc tests, \( P > 0.05 \)). The increase in TTMV immediately after lens insertion was similar among the three groups (\( P > 0.05 \)). Likewise, the decrease in TTMV over the next 30 minutes was similar among the three groups (\( P > 0.05 \)).

**DISCUSSION**

Understanding the differences in tear meniscus dimensions within the eye and how they differ between symptomatic and asymptomatic individuals may provide insight to the origins of dry eye disease. Further research is needed to determine the mechanism underlying these differences and whether they contribute to the development or worsening of dry eye.

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**TABLE 1.** Repeatability on Two Consecutive Days of Tear Meniscus Volumes 30 minutes after Lens Insertion

<table>
<thead>
<tr>
<th>Variables (µL)</th>
<th>Group</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 1 − Day 2 [SD]</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTMV</td>
<td>1</td>
<td>0.40 ± 0.06</td>
<td>0.40 ± 0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>UTMV</td>
<td>2</td>
<td>0.46 ± 0.05</td>
<td>0.46 ± 0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>UTMV</td>
<td>3</td>
<td>0.54 ± 0.04</td>
<td>0.54 ± 0.05</td>
<td>0.02</td>
</tr>
<tr>
<td>LTMV</td>
<td>1</td>
<td>0.55 ± 0.08</td>
<td>0.55 ± 0.09</td>
<td>0.02</td>
</tr>
<tr>
<td>LTMV</td>
<td>2</td>
<td>0.65 ± 0.10</td>
<td>0.65 ± 0.10</td>
<td>0.01</td>
</tr>
<tr>
<td>LTMV</td>
<td>3</td>
<td>0.64 ± 0.13</td>
<td>0.67 ± 0.06</td>
<td>0.10</td>
</tr>
</tbody>
</table>

There were no significant differences between the 2 days within each group (\( P > 0.05 \)). There were also no significant differences in the differences (day 1 − day 2) between the 2 days among the three groups. Group 1, adapted contact lens wearers with dry eye complaints; group 2, adapted contact lens wearers without dry eye complaints; group 3, non-contact lens wearers without dry eye complaints.

**TABLE 2.** Tear Meniscus Volumes around Contact Lenses

<table>
<thead>
<tr>
<th>Variables (µL)</th>
<th>Group</th>
<th>Baseline *</th>
<th>Insertion *</th>
<th>30 Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTMV</td>
<td>Group 1</td>
<td>0.40 ± 0.09</td>
<td>0.53 ± 0.11</td>
<td>0.46 ± 0.09</td>
</tr>
<tr>
<td>UTMV</td>
<td>Group 2</td>
<td>0.48 ± 0.09</td>
<td>0.60 ± 0.09</td>
<td>0.46 ± 0.09</td>
</tr>
<tr>
<td>UTMV</td>
<td>Group 3</td>
<td>0.54 ± 0.08</td>
<td>0.64 ± 0.09</td>
<td>0.54 ± 0.08</td>
</tr>
<tr>
<td>LTMV</td>
<td>Group 1</td>
<td>0.53 ± 0.12</td>
<td>0.68 ± 0.15</td>
<td>0.55 ± 0.10</td>
</tr>
<tr>
<td>LTMV</td>
<td>Group 2</td>
<td>0.66 ± 0.13</td>
<td>0.81 ± 0.12</td>
<td>0.65 ± 0.13</td>
</tr>
<tr>
<td>LTMV</td>
<td>Group 3</td>
<td>0.71 ± 0.07</td>
<td>0.86 ± 0.11</td>
<td>0.67 ± 0.07</td>
</tr>
</tbody>
</table>

* The lines indicate significant differences among checkpoints in any variables of each group (\( P < 0.005 \)).
† The brackets indicate significant differences of variables among groups at any checkpoint (baseline, CL insertion, and 30 minutes, \( P < 0.05 \)).

**FIGURE 3.** Upper, lower and total tear meniscus volumes before and after lens insertion. UTMV and LTMV in all the three groups increased significantly immediately after lens insertion (\( P < 0.005 \)) and recovered to baseline 30 minutes later (\( P > 0.05 \)). UTMV and LTMV in group 1 (G1) was the lowest, whereas UTMV in group 3 (G3) was the highest at each checkpoint (\( P < 0.05 \)). Differences in LTMV between groups 2 (G2) and 3 were not significant at all the time points (\( P > 0.05 \)) except at lens insertion where LTMV in group 3 was higher than that in group 2 (\( P < 0.05 \)).
dry eye symptoms. Previous studies limited the measurement to the height and radius of the lower tear meniscus as an indicator of tear volume.\textsuperscript{4,14,19–24} Using meniscometry, Maruyama et al.\textsuperscript{4} investigated changes in tear dynamics in soft lens wearers under different environmental conditions. They found no changes in the lower tear meniscus curvature at the lens interface. Miller et al.\textsuperscript{14} compared tear volumes measured by the phenol red thread test and lower tear meniscus height in wearers of different types of contact lenses. They found a trend toward lower tear volumes in the soft lens wearers. No information appears to be available regarding the upper tear meniscus, especially in lens wearers with dry eye symptoms. Wang et al.\textsuperscript{15,25} first used real-time OCT to image the upper and lower tear menisci and tested the changes after instillation of artificial drops. The method has been validated and widely used to study the tear system in various conditions, like the changes after blinking, artificial tear instillation, and contact lens wear in normal subjects.\textsuperscript{15,19–26} In the present study, this method was used for the first time to evaluate the tear volume around the contact lenses in subjects with symptoms of dry eye. The repeatability of the real-time OCT measurements on two consecutive days was good in all the groups and similar in each of the three groups. This result indicates that the method has good reliability when comparisons are made among groups. Wang et al.\textsuperscript{15,16} and Shen et al.\textsuperscript{17} reported similar findings for tear meniscus dimensional variables.

The mechanism and associated factors of dry eye sensations that occur during contact lens wear have been intensively studied.\textsuperscript{7,27–31} Contact lens wearers reduce lens wearing time mainly due to ocular discomfort, dryness, red eye, irritation, and even poor vision associated with soft contact lens wear.\textsuperscript{7} Of these factors, the first three are most important in discontinuation of lens wear. In the present study, the tear volume in symptomatic wearers was much lower than that in asymptomatic subjects both before and 30 minutes after lens insertion. Mainstone et al.\textsuperscript{32} found the tear volume, measured as tear meniscus curvature, height, and area, was lower in non-lens-wearing patients with dry eye than normal control subjects. As with the subjects in that study, the decreased tear volume in our lens-wearing subjects played a significant role in dry eye sensations and the mechanism of these sensations may be similar.

Reflex tearing often occurs at lens insertion and stops after a short period of adaptation time.\textsuperscript{19} Our data quantified the reflex tearing and recovery of tear volume after 30 minutes in all groups. The prelens tear film also increases immediately after blinking, artificial tear instillation, and contact lens wear in normal subjects.\textsuperscript{15,19–26} In the present study, this method was used for the first time to evaluate the tear volume around the contact lenses in subjects with symptoms of dry eye. The repeatability of the real-time OCT measurements on two consecutive days was good in all the groups and similar in each of the three groups. This result indicates that the method has good reliability when comparisons are made among groups. Wang et al.\textsuperscript{15,16} and Shen et al.\textsuperscript{17} reported similar findings for tear meniscus dimensional variables.

The present study showed that subjects with dry eye symptoms had lower tear meniscus volumes on the ocular surface, as well as the lower TBUT and Schirmer’s test results. The lower tear volumes may be responsible for the onset of dry eye symptoms. The tear volume at baseline and 30 minutes after lens wear was the smallest in group 1. No information was available for group 1 subjects regarding the presence of conditions that might have existed before they first wore their lenses. Thus, we do not know if the lens wear exacerbated a preexisting marginally dry eye or if their symptoms were due strictly to wearing lenses. The tear volume in group 2 subjects, as estimated by both tear meniscus volumes and Schirmer’s test results, was smaller than that in group 3 subjects. However, the volume of tears in the group 2 subjects may have been adequate to avoid dry eye symptoms. It is possible that the group 2 subjects will develop dry eye symptoms in the future if the tear volume becomes lower. To our knowledge, there is no study that follows the decline in tear secretion after several years of lens wear. Further studies are needed to address the effect on the tear system of wearing contact lenses for a long period.

Many contact lens wearers complain of ocular dryness and discomfort, especially late in the day.\textsuperscript{55} Wang et al.\textsuperscript{15} found no significant decreases in the tear menisci of normal subjects after 4 hours of lens wear. This suggests that short-term lens wear may not influence tear volume in normal, inexperienced lens wearers, and thus may not induce dryness. However, not much is known about the variation of tear volumes after lens wear for 10 hours or overnight, especially in subjects with dryness sensations. Tear volumes after long periods of lens wear will be the subject of another study. In addition, the pre- and postlens tear film dimensions were not measured in the present study. An understanding of the changes in these variables will provide additional insight about the effects of lenses on the tear system, and these questions will be examined in a future study. Other measurement errors have been previously detailed in other studies.\textsuperscript{15–17}

In summary, with and without lenses in situ, the tear volume in lens wearers with symptomatic dry eye was lower than that in asymptomatic experienced and new contact lens wearers. Alteration of the tear system during contact lens wear may contribute to the dry eye sensations. OCT is a useful tool to rapidly and invasively measure tear volume on contact lenses of patients with symptomatic dry eye.

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References