Tear Meniscus Volume in Dry Eye after Punctal Occlusion

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PURPOSE. To use optical coherence tomography (OCT) to evaluate the effect of punctal occlusion on tear meniscus volume in dry eye patients.

METHODS. Occlusion of both upper and lower puncta with collagen plugs was performed on one eye each in 20 dry eye patients and 20 normal subjects. The upper and lower tear menisci were imaged simultaneously by real-time OCT before punctal occlusion and on days 1, 4, 7, and 10 afterward. The heights, cross-sectional areas, and volumes of the menisci were obtained. Schirmer I test with anesthesia and tear break-up time (TBUT) testing were also performed.

RESULTS. At baseline, both upper and lower tear meniscus heights and volumes in dry eye patients were lower than those in control subjects (P < 0.05). The volume of the lower tear meniscus was 0.28 ± 0.09 mL in dry eye patients and 0.55 ± 0.22 μL in control subjects at baseline (P < 0.05). After punctal occlusion, the Schirmer I test scores of dry eye patients did not change (P > 0.05), but the heights and volumes of the upper and lower tear menisci increased (P < 0.05). In control subjects, Schirmer I test scores decreased (P < 0.05), but their heights and volumes of the upper and lower tear menisci did not change (P > 0.05).

CONCLUSIONS. Punctal occlusion induced increases in the upper and lower tear meniscus volumes in dry eye patients. The absence of change in the tear menisci of control eyes may indicate the presence of an autoregulatory mechanism in the tear system that maintains a balance in the tear volume. (Invest Ophthalmol Vis Sci. 2010;51:1965–1969) DOI:10.1167/ iovs.09-4349

Tears are produced by the lacrimal gland and held in the upper and lower tear menisci, from which they spread onto the ocular surface. The tear menisci hold approximately 75% to 90% of the total tear volume of the exposed ocular surface. During blinking, the tears are distributed, to wet and smooth the ocular surface and to maintain ocular health and sharp vision. Some of the tear fluid evaporates and the rest drains through the lacrimal puncta. The tear system is highly dynamic, and balance is maintained by tear secretion, drainage, and evaporation. The reduction of tear menisci in dry eye patients has been well documented and is regarded as a valuable diagnostic tool for dry eye. Insufficiency of tears is associated with dry eye symptoms, including ocular discomfort and irritation. The attempt to maintain a normal tear volume is a logical approach to dry eye therapy. Since first introduced by Foulds in 1961, punctal occlusion has become a common nonpharmacologic treatment for dry eye. It reduces symptoms and improves the Schirmer test score, tear break-up time, vital staining score, mucin goblet cell density, and functional visual acuity. In the present study, the effect of punctal occlusion on the tear menisci was determined in dry eye patients and compared to that in normal subjects who underwent the same procedure.

METHODS

Subjects

This research was approved by the Wenzhou Medical College Review Board, Wenzhou, Zhejiang, China, and was conducted in accordance with the tenets of the Declaration of Helsinki. Informed consent was obtained from each subject after a full explanation of the procedure. Twenty patients with clinically diagnosed dry eye (15 women and 5 men; mean ± SD age, 25.8 ± 6.5 years; range 20–31) and 20 healthy subjects (16 women and 4 men; mean ± SD age, 22.6 ± 2.3 years; range 20–36) were recruited. The diagnostic criteria of dry eye was similar to that used by the Japanese Dry Eye Society: presence of subjective symptoms of dry eye, Schirmer I test score <5 mm, or tear break-up time (TBUT) <5 seconds, and evidence of corneal surface damage on fluorescein staining. All 20 dry eye cases were non-Sjögren syndrome-type dry eye. The healthy subjects served as the control group and had no current ocular or systemic diseases. Subjects were excluded if they had a history of conjunctival, scleral, or corneal diseases or of eye surgery, glaucoma, diabetes mellitus, or thyroid disorder or if they were taking antidepressant or diuretic medication or wore contact lenses.

Upper and Lower Tear Menisci

The real-time optical coherence tomography (OCT) instrument in this study was the same as we used in other studies. In brief, the OCT system light source had a 1310-nm wavelength with a 60-nm bandwidth and was mounted on a standard slit lamp with a probe connected to a telecentric light delivery system. The scan width was up to 15 mm with a scan speed of 8 frames per second. The scan depth was set to 2 mm in air, and the optical resolution was approximately 10 μm. During scanning, subjects were instructed to fix on an external target and blink normally. The images were recorded as the OCT device scanned vertically across the apex of the cornea. The first good image taken immediately after a blink and showing both upper and lower tear menisci was used in the analysis. In addition, during the first
visit, the eye was photographed with a digital camera mounted on a slit lamp with a reference scale to yield the length of both upper and lower eyelids.

Custom software was used to process the images, with operator inputs obtained by identifying the middle point of the tear meniscus front edge and touch points between the eyelids, cornea, and tear menisci, as detailed elsewhere.\(^1\)\(^2\) Upper tear meniscus height (UTMH), upper tear meniscus cross-sectional area (UTMA), lower tear meniscus height (LTMH), and lower tear meniscus cross-sectional area (LTMV) were obtained by software analysis of the images. Tear meniscus volumes in the upper and lower tear menisci (UTMV and LTMV, respectively) were also calculated as the product of the lid length, tear meniscus cross-sectional area, and the factor of 1.294, as described in a previous study.\(^1\)\(^2\)

**Schirmer I Test**

Tear production was measured by the Schirmer I test with anesthesia. Five minutes after instillation of a drop of proparacaine (Alcon, Puurs, Belgium), the test was performed by placing a dry Schirmer test strip (Jingming, Tianjing, China) over the lower lid margin into the tear lake at the junction of the middle and lateral one third of the eye lid for 5 minutes. The strip was then removed, and the amount of wetting in millimeters was recorded as the Schirmer I test score.

**Tear Break-up Time**

Tear film stability was estimated based on TBUT. A fluorescein-impregnated strip (Jingming) wetted with nonpreservative saline solution was placed in the lower conjunctival sac. After one blink, the time to appearance of the first nonstained spot in the stained tear film was recorded.

**Procedure**

All subjects were tested between 10 AM and 4 PM in a dimly lit consulting room where the temperature (15–25°C) and humidity (30%–50%) were controlled by air conditioning and a dehumidifier. During the first visit, both upper and lower tear meniscus images, Schirmer I test scores, and TBUT were obtained from one randomly selected eye of each subject. Absorbable collagen plugs (Lacrimecids, Eastsound, WA) were then implanted into both the upper and lower puncta of the selected eye. All the collagen plugs were 0.4 mm in diameter and 1.75 mm in length, and they were reported by the manufacturer to dissolve in 4 to 7 days. The OCT images and Schirmer I test scores were obtained again on the follow-up visits at 1, 4, 7, and 10 days after punctal occlusion. The TBUT was again determined at 4 days after punctal occlusion.

**Data Analysis**

All data are presented as the mean ± standard deviation. Independent-samples t-tests were used to compare Schirmer I test scores, TBUT, and tear meniscus heights and volumes between groups. Paired-samples t-tests were used to compare the TBUT before and 4 days after punctal occlusion. Repeated-measures analysis of variance (Re-ANOVA) and post hoc tests were used to assess the changes in the tear meniscus and Schirmer I test scores after punctal occlusion. The Pearson correlation coefficient was used to determine the correlation between variables (software for all analyses: SPSS ver. 13 for Windows; SPSS, Chicago, IL). \(P < 0.05\) was accepted as statistically significant.

**Results**

Upper and lower tear menisci in dry eye patients and control subjects were clearly visualized at baseline and after punctal occlusion (Fig. 1). At baseline, the Schirmer I test score in the dry eye patients (5.5 ± 5.1 mm) was significantly lower than that in the control subjects (16.9 ± 11.2 mm, independent-samples t-test, \(P < 0.05\), Table 1). After punctal occlusion, there was no significant change in Schirmer I test scores in the dry eye patients over time, compared with baseline (post hoc test, \(P > 0.05\), Table 1, Fig. 2). However, in the control subjects, Schirmer I test scores recorded 7 and 10 days after punctal occlusion were significantly lower than those at baseline (\(P < 0.05\), Table 1, Fig. 2). At 7 and 10 days after punctal occlusion, there were no significant differences in Schirmer I test scores between the dry eye and control groups (independent-samples t-test, \(P > 0.05\), Table 1).

At baseline, the TBUT in the dry eye patients, 4.7 ± 2.7 seconds, was significantly lower than that in the control subjects (9.7 ± 4.2 seconds, independent-samples t-test, \(P < 0.05\)). At 4 days after punctal occlusion, the TBUT in the dry eye patients increased to 8.9 ± 9.0 seconds (paired t-test, \(P < 0.05\)) compared with baseline. There were no significant differences in TBUT between the dry eye and control groups at 4 days after occlusion (independent-samples t-test, \(P > 0.05\)).

At baseline and 1 day after punctal occlusion, both upper and lower tear meniscus heights and volumes in the dry eye patients were lower than those in the control subjects (independent-samples t-test, \(P < 0.05\), Table 1). Typically, LTMV was 0.28 ± 0.09 μL in the dry eye patients and 0.55 ± 0.22 μL in the control subjects at baseline (\(P < 0.05\)). However, at 4 and 7 days after punctal occlusion, there were no significant differences in tear meniscus heights or volumes between the groups (independent-samples t-test, \(P > 0.05\), Table 1). In the dry eye patients, compared with baseline, both upper and lower tear menisci heights and volumes increased significantly at 1, 4, and 7 days after punctal occlusion (post hoc test, \(P < 0.05\), Table 1, Figs. 1, 2). Except for UTMH, all of them returned to baseline at 10 days. In contrast, in the control subjects there were no significant differences in meniscus heights or volumes between baseline values and any day after punctal occlusion (post hoc test, \(P > 0.05\), Table 1, Figs. 1, 2).
was no significant correlation between Schirmer test scores and tear volumes for either study group ($P > 0.05$). The $r$-values ranged from 0 to 0.36 in the dry eye group and from 0 to 0.37 in the control group.

**DISCUSSION**

OCT is a noncontact, noninvasive imaging modality that has been used to study the effect of blinking on tear dynamics.\(^{15}\) In the present study, OCT imaged the tear menisci after punctal occlusion in dry eye patients and normal subjects. There are some previous studies on the effect of punctal occlusion on the tear meniscus.\(^{14–17}\) In those studies, either videotaping or tear interferometry was used to capture the image of the lower tear meniscus. Both methods required that a bright light be directed onto the eye during measurements, and it is possible that the light caused excess tearing. Compared with those instruments, the custom OCT instrument has two advantages. One is that no visible light is used. The other is that it can image the upper and lower tear menisci simultaneously in real time.

In the present study, punctal occlusion with collagen plugs appeared to improve both tear retention time and tear volumes in the dry eye patients. Four days after occlusion, the TBUT in the dry eye patients reached almost normal levels. Both the upper and lower tear meniscus heights and volumes were increased to near normal levels at 4 and 7 days after punctal occlusion but appeared to decline afterward, possibly because the plug dissolved. In contrast, the TBUT, as well as tear volumes in normal subjects did not

### Table 1. Schirmer I Test Scores and Tear Meniscus Heights and Volumes after Punctal Occlusion

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Day 1</th>
<th>Day 4</th>
<th>Day 7</th>
<th>Day 10</th>
<th>Re-ANOVA</th>
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<tr>
<td>Schirmer test, mm</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Dry eye</td>
<td>5.5 ± 5.1*</td>
<td>7.0 ± 9.3*</td>
<td>7.3 ± 8.4*</td>
<td>8.8 ± 10.6</td>
<td>7.2 ± 7.2</td>
<td>$P = 0.259$</td>
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<tr>
<td>Control</td>
<td>16.9 ± 11.2</td>
<td>17.2 ± 10.1</td>
<td>14.3 ± 10.4</td>
<td>10.2 ± 9.9†</td>
<td>9.2 ± 8.9†</td>
<td>$P = 0.001$</td>
</tr>
<tr>
<td>UTMH, μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry eye</td>
<td>164 ± 30*</td>
<td>195 ± 36†</td>
<td>200 ± 57†</td>
<td>210 ± 35†</td>
<td>195 ± 33†</td>
<td>$P &lt; 0.001$</td>
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<tr>
<td>Control</td>
<td>217 ± 31</td>
<td>225 ± 39</td>
<td>218 ± 39</td>
<td>217 ± 42</td>
<td>219 ± 39</td>
<td>$P = 0.927$</td>
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<tr>
<td>LTMH, μm</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Dry eye</td>
<td>192 ± 29*</td>
<td>229 ± 35†</td>
<td>229 ± 66†</td>
<td>244 ± 40†</td>
<td>215 ± 37*</td>
<td>$P = 0.001$</td>
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<tr>
<td>Control</td>
<td>251 ± 36</td>
<td>276 ± 65</td>
<td>250 ± 65</td>
<td>253 ± 85</td>
<td>265 ± 54</td>
<td>$P = 0.296$</td>
</tr>
<tr>
<td>UTMV, μL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry eye</td>
<td>0.22 ± 0.08*</td>
<td>0.33 ± 0.12†</td>
<td>0.35 ± 0.19†</td>
<td>0.38 ± 0.13†</td>
<td>0.32 ± 0.13*</td>
<td>$P = 0.001$</td>
</tr>
<tr>
<td>Control</td>
<td>0.43 ± 0.14</td>
<td>0.44 ± 0.16</td>
<td>0.42 ± 0.17</td>
<td>0.40 ± 0.17</td>
<td>0.41 ± 0.14</td>
<td>$P = 0.838$</td>
</tr>
<tr>
<td>LTMV, μL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry eye</td>
<td>0.28 ± 0.09*</td>
<td>0.44 ± 0.15†</td>
<td>0.50 ± 0.36†</td>
<td>0.48 ± 0.15†</td>
<td>0.38 ± 0.18*</td>
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<td>0.55 ± 0.22</td>
<td>0.66 ± 0.32</td>
<td>0.55 ± 0.35</td>
<td>0.60 ± 0.53</td>
<td>0.63 ± 0.35</td>
<td>$P = 0.689$</td>
</tr>
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</table>

* $P < 0.05$ compared to control subjects.
† $P < 0.05$ compared to baseline.

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**FIGURE 2.** Schirmer I test scores and tear meniscus heights and volumes after punctal occlusion in dry eye patients and control subjects. Schirmer I test scores did not change in the dry eye patients after punctal occlusion (top left, post hoc test, $P > 0.05$) but decreased at days 7 and 10 after occlusion in the control subjects (top right, post hoc test, $P < 0.05$). Both tear meniscus heights and volumes increased after punctal occlusion in the dry eye patients (middle left, bottom left, post hoc test, $P < 0.05$). In the control subjects, there were no changes after punctal occlusion for heights and volumes of upper and lower tear menisci (middle right, bottom right, post hoc test, $P > 0.05$). Significant differences in the variables compared to baseline ($P < 0.05$).
deficient dry eye patients and found that the LTMH increased the lower puncta with dissolvable collagen plugs in aqueous-ocular system. These changes may also alter or reduce drainage patients, recovery of tear volume may override the proposed lower tear meniscus increased to the normal range. In dry eye Sjögren syndrome. Three weeks after punctal occlusion, the superior and inferior punctal occlusion in dry-eye patients with some tears may have been preserved.

In this study, punctal occlusion may further block the drainage; thus, gests reduced drainage even without punctal occlusion. It is possible that blockage of the puncta affects elements of the autoregulatory system located in the puncta, associated canaliculi, and/or lacrimal sac, and thus inhibits secretion of tears by the main and accessory lacrimal glands. The finding, but not statistically significant, increase in tear meniscus volume on day 1 after occlusion may induce some inhibitory effect triggered by the neurosensory autoregulatory system. This possibility warrants further investigation. In normal eye, only a small volume of tears is needed, and very little volume is lost to the drainage system during normal blinking (Yuan Y, et al. IOVS 2009;50:ARVO E-Abstract 1233). Farrell et al. found an inverse relationship between baseline LTMH and change in LTMH after punctal occlusion. Clearly, a balanced tear system, regulated to maintain a certain amount of high-quality tears, is very important for optimal visual quality and protection of the ocular surface.

Recovery of tear volume to near-normal levels after punctal occlusion was evident in the dry eye patients and is in agreement with data in other studies. Farrell et al. occluded the lower puncta with dissolvable collagen plugs in aqueous-deficient dry eye patients and found that the LTMH increased to normal levels. Uchida et al. studied the efficacy of both superior and inferior punctal occlusion in dry-eye patients with Sjögren syndrome. Three weeks after punctal occlusion, the lower tear meniscus increased to the normal range. In dry eye patients, recovery of tear volume may override the proposed autoregulatory system, due to the demand for tears in the ocular system. These changes may also alter or reduce drainage capability. Yuan et al. (IOVS 2009;50:ARVO E-Abstract 1233) found that the blinking output in the lower tear meniscus in aqueous-deficient dry eye patients was reduced, which suggests reduced drainage even without punctal occlusion. It is unclear whether the decrease in drainage was due to lower tear volume or was the result of autoregulation. In the present study, punctal occlusion may further block the drainage; thus, some tears may have been preserved. Another possible explanation for the increase in postocclusion tear volume in dry eye is increased tear secretion; however, the increase in the Schirmer test scores in the anesthetized eyes after occlusion did not reach statistical significance in this study. The Schirmer test measures the tearing that occurs with tear secretion. This test may not necessarily reflect the tear retention on the ocular surface that is due to punctal occlusion, which reduces tear drainage. In the present study, no significant changes in Schirmer test results were evident, whereas the tear meniscus volume increased in the dry eye patients. Our findings are in agreement with those of Burgess et al., who reported that the change in Schirmer test scores in dry eye patients after punctal occlusion did not reach statistical significance, whereas the change in tear meniscus heights did. The short survival time of the collagen plugs did not induce obvious improvement in tear secretion; perhaps occlusion with nonabsorbable plugs would lead to a significant increase. Several studies have documented increased Schirmer test scores after punctal occlusion in dry eye patients. The exact mechanism by which punctal occlusion increases tear secretion is not very clear. Perhaps the underlying cause of aqueous tear deficiency in dry eye patients is excessive negative feedback from the ocular surface or the tear drainage apparatus on secretion of tears by the lacrimal gland. Placing a plug in the puncta may in some way reverse this process.

Clearly the condition of the ocular surface is improved by increased tear volume, as documented by the better tear film stability, decreased ocular surface staining scores, and squamous metaplasia grades, and increased goblet cell density. However, in some cases, there may be adverse responses. For instance, punctal occlusion may exacerbate ocular surface inflammation in subjects with clinically overt inflammatory disease. Restoring tear quality may be more important than retaining tear volume. Roberts et al. reported that combined use of punctal occlusion and cyclosporine produced better improvements in Schirmer test scores, rose bengal staining, and reducing overall artificial tear use than did either treatment alone.

Both UTMH and LTMV increased in the present study, which may indicate that there is a physical and functional connection between them. The similar change in upper and lower tear meniscus indicates that they may be hydraulically connected and serve as a unit in the tear reservoir. During the open-eye period, freshly secreted tears are collected in the upper tear meniscus and then transferred into the lower meniscus via the connection at the junctions between the upper and lower lids. As the upper lid moves vertically during blinking, the tears from the upper tear meniscus spread over the ocular surface, and the lower tear meniscus thus maintain communication as the eyelid moves continuously.

There are some limitations in the present study. First, the degradation time of the collagen plugs may have varied between subjects. However, follow-up on days 1, 4, 7, and 10 and Re-ANOVA should reflect the effect of punctal occlusion. Second, the palpebral aperture was not precisely controlled during the measurements, and some errors may have been introduced. By instructing subjects to look straight ahead and blink normally, we attempted to minimize this error. Even if an error occurred, it had little effect on detecting differences between dry eye patients and normal subjects.

In summary, short-term punctal occlusion during a 10-day period had no effect on tear volume in normal subjects. However, it did increase tear volume for 7 days in the upper and lower menisci of dry eye patients. These results suggest an autoregulatory mechanism in the tear system, into which further investigation is needed.

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References


