Tear Evaporation Dynamics in Normal Subjects and Subjects with Obstructive Meibomian Gland Dysfunction

Eiki Goto, Koji Endo, Atsushi Suzuki, Yoshiaki Fujikura, Yukihiro Matsumoto and Kazuo Tsubota

Purpose. To test a newly developed tear evaporimetry system that detects real-time changes in tear evaporation rates and shows the tear film stability in patients with obstructive meibomian gland dysfunction (MGD).

Methods. A ventilated chamber system with high-sensitivity microbalance sensor was used to evaluate tear evaporation. Tear evaporation rates and dynamic changes in them in response to blinking (“flip heights”) were measured. Both were compared in 38 eyes of 22 normal subjects and 32 eyes of 21 patients with obstructive MGD, in a prospective case–control study. The relationship between tear evaporation rates and flip heights to meibomian gland orifice obstruction was also analyzed.

Results. Changes in tear evaporation rates produced by blinking were detected. The tear evaporation rates in the patients’ group were 5.8 ± 2.7(10^-7) g/cm² per second, significantly higher than in normal subjects (4.1 ± 1.4(10^-7) g/cm² per second; P = 0.0008). The flip heights in the obstructive MGD group were 0.58 ± 0.35(10^-7) g/cm² per second, significantly higher than in normal subjects (0.39 ± 0.27(10^-7) g/cm² per second, P = 0.02). The correlations between both tear evaporation rates and flip heights to the meibomian gland orifice obstruction score were statistically significant (P < 0.0001 and P = 0.004, respectively).

Conclusions. This new system was helpful in differentiating MGD patients from normal subjects. These significantly higher evaporation rates and higher flip heights reflect the unstable tear evaporation and may well indicate unstable tear film in patients with obstructive MGD with abnormal evaporative tear loss. (Invest Ophtalmol Vis Sci. 2003;44:533-539) DOI: 10.1167/iovs.02-0170

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From the 1Department of Ophthalmology, Tokyo Dental College, Chiba, Japan; the 2Department of Ophthalmology, Keio University School of Medicine, Tokyo, Japan; the 3Analytical Research Center, and the 4Health Care Products Research Laboratories No. 2, KAO Corporation, Tokyo, Japan.

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Corresponding author: Kazuo Tsubota, Department of Ophthalmology, Tokyo Dental College, 5-11-13 Sugano, Ichikawa-cho, Chiba 272-8513, Japan; eikigoto@nifty.com.

differentiating dry eye syndrome subcategories—that is, aqueous tear deficiency (ATD) dry eye and lipid tear deficiency (LTD) dry eye (also known as evaporative dry eye)1-4 and for evaluating treatment efficacy.3

The lacrimal glands secrete aqueous tears. They are distributed over the ocular surface by blinking, drain into the lacrimal punctum, and evaporate into the air.7 Aqueous tears are covered by tear lipid secreted by the meibomian glands that spreads to form an oily layer of precorneal tear film. Meibomian gland secretion limits evaporative tear loss, provides a barrier function at the lid margin, supplies lubrication during blinking, and maintains an optically smooth surface.7-13

Tear dynamics have been studied by Schirmer test,14 by the cotton thread test,15,16 with meniscometers,17 with tear evaporimeters,3-6 by measuring turnover rates by tear clearance and the tear-function index,7,18-20 and by tear interference.21-25 Also, tear stability has been studied with fluorescein tear break-up time (BUT).15,26-27 BUT has been considered a practical method to indicate tear stability. However, the instillation of fluorescein dye is not a fully noninvasive procedure.

In the evaluation of dry eye syndrome with abnormal tear dynamics, despite clear criteria for ATD,4,15 the diagnosis of evaporative dry eye, mainly represented by obstructive meibomian gland dysfunction (MGD)—that is, undetectable by tear measurement of secretion by Schirmer’s test—is made indirectly by examining morphologic changes in the meibomian glands,20 by meibography,20 by semiquantification of case of meibum (mebomian gland secretion) expression with digital compression,1,2 by quantification of lid margin meibum by meibometry,22,30 by semiquantification of the presence of tear lipid by tear interference,22-25,31 and by a combination of dye staining and impression cytology,32 or it is inferred by demonstrating rapid tear evaporation.1,2,35

Obstructive MGD is the major cause of lipid tear deficiency and evaporative dry eye and has recently attracted attention as a cause of ocular discomfort.2,15,32 Obstructive MGD decreases the lipid supply, which in turn leads to decreased tear stability, loss of lubrication, and damage to the ocular surface epithelium, thus producing symptoms.2,15,32

Tear evaporation measurements are noninvasive, and they are essential for identifying tear dynamics, differentiating between dry eye subcategories including evaporative dry eye, and evaluating results of treatment.1-6,15 Human tear evaporation rates have been reported, and differences between the results in normal subjects and patients with dry eye vary with the methods used.3,4,6 Also, humidity-sensing systems in previous reports have a slower response that may not measure quick changes in tear evaporation, and they do not incorporate recent advances in computer technology.

We thought that if we could develop a system to measure tear evaporation with a more rapidly responding humidity sensor and sophisticated software, we would be able to investigate real-time dynamic changes in tear evaporation, which would be more helpful in differentiating dry eye subcategories.15,35 In this article we report the development of a new
system to measure tear evaporation rates and dynamic changes by blinking, which represents the stability of the tear film, by using a microbalance, high-sampling-rate humidity sensor, and sophisticated software for real-time measurement and analysis.

METHODS

Tear Evaporimeter Setup

Tear evaporation from the ocular surface was evaluated by making the following measurements. Briefly, the evaporimeter consisted of an eyecup in the form of a ventilated chamber having a volume of 20 cm$^3$ and tightly covering the eye; air, with known water content and infused into the cup as a tear evaporation carrier by an air compressor at a constant flow rate (150 mL/min), and a quartz crystal sensor (9 MHz A-T cut quartz crystal with 8 mm in diameter and 0.2 mm in thickness), known as the 'microbalance,' which has high sensitivity to humidity. The frequency of the sensor shifts in response to changes in humidity. Evaporation rates were measured by calculating the difference between the water content of the air entering and exiting the cup. The instrumental setup and schema are shown in Figures 1A, 1B, and 1C. Evaporation rates, $J$ (in grams per square centimeter per second), were calculated as follows

$$J = \frac{\Delta F \rho V}{kA}$$

Where $\Delta F$, is the frequency shift (in Hertz) between the measured value and the baseline value on the frequency counter, $\rho$ (in grams per cubic centimeter) is the water content of air having 100% RH at a given temperature, $V$ (in cubic centimeters per second) is the flow rate of the carrier gas, and $A$ (in square centimeters) is the area measured (Fig. 2). In this study, $A$ and $V$ were 13 cm$^2$ and 2.5 cm$^3$/sec, respectively. Room temperature was fixed at 22°C. Thus, $\rho$, $V$, $k$, and $A$ are all constants in this setup, and evaporation rates are proportional to $\Delta F$, the frequency shift (Fig. 2).

We measured evaporation rates with the eye closed, with the eye open (natural blinking), and with forced blinking every 5 seconds, twice the normal rate. To avoid the contribution of evaporation from lid skin, we calculated the differences between open and closed eyes. The tear evaporation rates from the ocular surface ($\Delta J$) were defined as the difference between two steady state evaporation rates (5 seconds, average of 20 data points): that with open eye (natural blinking) and with closed eye (transpiration from skin surface). Thus,

$\Delta J$ is the difference between the evaporation rates with the eye open and closed.

$$\Delta J = J_{\text{open}} - J_{\text{closed}}$$

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$\Delta J$ is the difference between the evaporation rates with the eye open and closed.

$$\Delta J = J_{\text{open}} - J_{\text{closed}}$$

When the eye was shut, the flip was descending, and when the eye started to open, the flip was ascending.

$\Delta F$ is the frequency shift between the measured value and the baseline value on the frequency counter.

$\Delta F = F_{\text{measured}} - F_{\text{baseline}}$
the evaporation rates from the ocular surface are proportional to the difference in frequency shift (Fig. 2)

\[ \Delta f = J_{\text{open eye}} - J_{\text{closed eye}} \]  

(2)

Flip heights (in grams per square centimeter per second), which appeared on the frequency profile of the forced blinking at the steady state, were estimated from the average height of each flip (flip heights in Fig. 2). Thus, flip heights can represent small changes in tear evaporation due to blinking. Software developed using commercial software (Visual Basic; Microsoft, Redmond, WA) was programmed for evaporation measurements, records, and analysis (programmed in Windows 98; Microsoft). The data sampling rate was four times a second. Real-time changes in the frequency data appeared on the display of a personal computer in synchrony with this sampling rate, and that allowed us to analyze tear evaporation dynamically.

**Examinations of Tears, the Ocular Surface, and Meibomian Glands**

The ocular surface was examined by the double-staining method. Preservative-free solution (2 \( \mu L \)) consisting of 1% fluorescein and 1% rose bengal dye was applied to the conjunctival sac. The intensity of rose bengal staining of the cornea and conjunctiva was recorded, with a maximum score of 9. Fluorescein staining of the cornea was also rated from 0 to 9. BUT was then measured three times, and the measurements were averaged.\(^{37}\) The Schirmer test was performed to measure tear secretion.\(^{14,18,38}\) The inclusion criteria for the diagnosis of obstructive MGD were the presence of meibomian gland dropout, poor meibum expression, and lack of active inflammation.\(^{1,2,29}\) A transillumination examination (meibography) was performed with a fiber-optic device (L-3920; Inami, Co., Tokyo, Japan).\(^{39}\) Loss of the visible structure of the meibomian glands (gland dropout) revealed by meibography was considered evidence of obstructive MGD, because this finding has been reported to be a good parameter for obstructive MGD-associated ocular surface changes.\(^{1,2-29}\) The degree of meibomian gland dropout was scored as described previously: grade 0, no gland dropout; grade 1, gland dropout in less than half of the inferior tarsus; and grade 2, gland dropout in more than half of the inferior tarsus.\(^{1,2}\) To assess expression of meibum and obstruction of the meibomian gland orifice, digital pressure was applied on the upper tarsus, and the degree of ease of expression of meibomian secretion (meibum) was evaluated semiquantitatively as follows: grade 0, clear meibum easily expressed; grade 1, cloudy meibum expressed with mild pressure; grade 2, cloudy meibum expressed with more than moderate pressure; and grade 3, meibum cannot be expressed even with intense pressure.\(^{1,2}\)

**Subjects**

We tested 38 eyes of 22 consecutive normal subjects (10 men and 12 women; average age, 39.5 \( \pm \) 9.5 years) and 52 eyes of 21 patients with obstructive MGD (9 men and 12 women; average age, 46.0 \( \pm \) 14.4 years). Both eyes or only the right eye were measured.

The normal subjects had clear corneas and conjunctivae (as assessed by slit-lamp biomicroscopy with fluorescein staining), no clinical manifestations, a normal Schirmer test result (25.3 \( \pm \) 10.3 mm), and a normal meibomian gland orifice obstruction score (0.4 \( \pm \) 0.5). The patients with obstructive MGD had normal Schirmer test results (21.7 \( \pm \) 10.5 mm), with vital staining of the corneas or conjunctivae with fluorescein (0.06 \( \pm \) 0.4) and rose bengal (0.3 \( \pm \) 0.8), and a short BUT (4.6 \( \pm \) 3.1 second). The meibography score was 1.2 \( \pm \) 0.4, and the meibomian orifice obstruction score was 2.2 \( \pm \) 0.4 in the obstructive MGD group. None of the subjects had any evidence of ocular infection, were contact lens wearers, had had punctal occlusion performed, had blepharospasm or abnormal blinking. Complicated dry eye cases, such as Sjögren syndrome, Stevens-Johnson syndrome, and ocular pemphigoid were also excluded from the study. The research followed the tenets of the Declaration of Helsinki, and informed consent was obtained from all the subjects after explanation of the nature and possible consequences of the study.

**Main Outcome Measurement**

Tear evaporation rates and flip heights were compared between the two groups. In all subjects, the relationships between meibomian gland orifice obstruction score and both tear evaporation rates and flip heights were analyzed to investigate how the amount of lipid on the lid margin and ocular surface affects the evaporation rates and its dynamic changes.

**Tear Evaporation Rates Corrected with Ocular Surface Area**

In this report, we adopted the area of the eyelid for the evaporation rate calculation as a fixed value of 13 cm\(^2\), for real-time evaporation measurement (equation 1). Rolando and Refojo reported the tear evaporation rates divided by the exposed ocular surface area photographically.\(^3\) We also measured the exposed ocular surface area \((A')\) and palpebral aperture photographically with a charge-coupled device (CCD) camera (PCAM-VUA; NEC Corp., Tokyo, Japan) with image-analysis software (Scion Image, Scion Corp., Frederick, MD) in all 38 eyes of the normal subjects. The area and size of the aperture were measured as follows: an eye of each subject and a scale were taken in the same image. The area of exposed eye surface and the length of its palpebral aperture were measured on the image in the unit of pixel by image analysis. These values were converted to the unit of an actual dimension using the scale. The relationship (linear regression) between the exposed area and the size of the aperture was obtained (Fig. 5).

As the tear evaporation rates from the ocular surface \((\Delta f)\) were obtained by subtraction between two steady state evaporation rates, that is, open eye and closed eye\(^4\) (equation 2, which is a different method from Roland and Refojo\(^5\) using cream to suppress the evaporation from the skin surface), ocular evaporation rates \((\Delta f')\) by the exposed ocular surface area \((A')\) was calculated and corrected as follows:

\[ \Delta f' = J_{\text{open eye}} - J_{\text{closed eye}} \times (13 - A')/13 \]  

(3)

**FIGURE 3.** The exposed ocular surface area and the size of the palpebral aperture were obtained photographically in all 38 eyes of normal Asian subjects.\(^7\) Solid and dashed lines: results of linear regression and the 95% confidence interval: \(y = 0.22x - 0.55, r = 0.901, P < 0.0001\). Our results, obtained in Asian eyes were similar with the corresponding values reported by Rolando and Refojo (Western and Asian eyes, \(y = 0.28x - 0.44, r = 0.991\)).\(^5\)
For all obstructive MGD subjects, we adopted the averaged exposed ocular surface area of all normal subjects for correction, because we had not measured the exposed ocular surface area and the palpebral aperture size.

**Statistical Analysis**

All data are shown as the mean ± SD. The Mann-Whitney test was applied to tear evaporation rates and comparison of flip heights. Linear regression analysis was applied to relationships with meibomian gland orifice obstruction score. It was also applied to the relationship between exposed ocular surface area and palpebral aperture. \( P < 0.05 \) was accepted as statistically significant. Analyses were performed on computer (Instat 3.0 for Mac OS X; Graphpad Software, Inc., San Diego, CA).

**RESULTS**

**Tear Evaporation Rates and Flip Heights Analysis**

Tear evaporation rates by subject group are shown in Figure 5A. The tear evaporation rates (free blinking) of normal subjects were \( 4.1 \pm 1.4 (10^{-7}) \) g/cm\(^2\) per second, and were significantly higher, \( 5.8 \pm 2.7 (10^{-7}) \) g/cm\(^2\) per second, in the obstructive MGD group (Table 1, \( P = 0.0008 \)). Tear flip heights by subject group are shown in Figure 5B. The flip heights (at forced blinking every 5 seconds) of the normal subjects were \( 0.39 \pm 0.27 (10^{-7}) \) g/cm\(^2\) per second, and were significantly higher, \( 0.58 \pm 0.33 (10^{-7}) \) g/cm\(^2\) per second, in the obstructive MGD group (Table 1, \( P = 0.02 \)). The flip height–evaporation rate ratio was 9.48% in normal subjects and 9.89% in the obstructive MGD group.

**Relationship between Tear Evaporation Rates and Meibomian Gland Orifice Obstruction Scores**

Relationships to the meibomian gland orifice obstruction scores are shown in Figure 6A. A significant correlation was found between meibomian gland orifice obstruction scores and tear evaporation rates (\( r = 0.49, P = 0.0001 \)) in all normal subjects and in patients with obstructive MGD.

**Relationship between Flip Heights and Meibomian Gland Orifice Obstruction Scores**

The relationships to meibomian gland orifice obstruction scores are shown in Figure 6B. A significant relationship between meibomian gland orifice obstruction scores and flip heights was found (\( r = 0.37, P = 0.004 \)) in all normal subjects and in patients with obstructive MGD.

**FIGURE 4.** The tear evaporation rates of the normal subject are 4.5 \((10^{-7})\) g/cm\(^2\) per second, and the flip heights are 0.60 \((10^{-7})\) g/cm\(^2\) per second (A). The tear evaporation rates of the patients with obstructive MGD are 7.4 \((10^{-7})\) g/cm\(^2\) per second, and the flip heights are 1.2 \((10^{-7})\) g/cm\(^2\) per second (B).

**FIGURE 5.** The tear evaporation rates (A, free blinking) and flip heights (B, forced blinking) in the MGD group were significantly higher than in the normal subjects.
Table 1. Comparison of Our Tear Evaporation Rates with the Values in Literature

<table>
<thead>
<tr>
<th>Study</th>
<th>Dry Eye (ATD)</th>
<th>Dry-Eye (PO)</th>
<th>MGD</th>
<th>MGD + ATD</th>
<th>SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hamano et al</td>
<td>26.9</td>
<td>15.2</td>
<td></td>
<td></td>
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<tr>
<td>Rolando and Refojo</td>
<td>4.07 ± 0.40</td>
<td></td>
<td>7.87 ± 2.80</td>
<td>8.03 ± 2.84</td>
<td></td>
</tr>
<tr>
<td>Rolando et al</td>
<td>4.07 ± 0.40</td>
<td></td>
<td>8.03 ± 2.84</td>
<td>8.03 ± 2.84</td>
<td></td>
</tr>
<tr>
<td>Shimazaki et al</td>
<td>8.3 ± 1.9†</td>
<td>4.6 ± 2.9†</td>
<td>9.5 ± 5.6‡</td>
<td>18.2 ± 4.8‡</td>
<td></td>
</tr>
<tr>
<td>Mathers et al</td>
<td>14.7 ± 6.4‡</td>
<td>47.6 ± 20.1‡</td>
<td>33.0 ± 12.4‡</td>
<td></td>
<td></td>
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<tr>
<td>Mathers and Lane</td>
<td>14.8 ± 6†</td>
<td></td>
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<tr>
<td>Shimazaki et al</td>
<td>13 ± 6†</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>This study</td>
<td>4.1 ± 1.4§</td>
<td></td>
<td>5.8 ± 2.7§</td>
<td>7.4 ± 2.8§</td>
<td></td>
</tr>
</tbody>
</table>

Data are the mean ± SD of $10^{-7}$ g/cm² per second. Depending on the methods, evaporation rates from ATD dry eye patients were lower than normal subjects in reports from 2 groups,1,3,6 but were higher in reports from 2 other groups.4,46 On the contrary, MGD or obstructive MGD patients were always shown to have higher evaporation rates than normal subjects, including this study.2,33 Flip heights of normal subjects and obstructive MGD patients were shown for the first time in this study. NL, normal subjects; ATD, aqueous tear deficiency; PO, punctal occlusion; MGD, meibomian gland dysfunction; SS, Sjogren’s syndrome; †, lower than normal results, using the same method; ‡, higher than normal results, using the same method; Flip, flip heights.

* Tear evaporation rates were reported as $10^{-7}$ g/sec.
† Tear evaporation rates at 40% ambient humidity.
‡ Tear evaporation rates at 30% ambient humidity.
§ Tear evaporation rates calculated within the area of the eye cup.

Relationship between the Exposed Ocular Surface Area and the Size of the Palpebral Aperture, Evaporation Rates, and Flip Heights, Corrected with the Exposed Ocular Surface Area

Figure 3 shows the relationship between the area of exposed ocular surface and its palpebral aperture (all Asian eyes). The line in Figure 3 represents the regression results; $y = 0.22x - 0.55$, $r = 0.901$, $P < 0.0001$. Our results, obtained in Asian eyes, were similar to the corresponding values reported by Rolando and Refojo (Western and Asian eyes, $y = 0.28x - 0.44$, $r = 0.991$).5 When we use the exposed ocular surface area for calculation, the tear evaporation rates (free blinking) of normal subjects were $5.7 ± 1.4 (10^{-7})$ g/cm² per second and were significantly higher, $7.4 ± 2.8 (10^{-7})$ g/cm² per second, in the obstructive MGD group (Table 1, $P = 0.001$). The flip heights (at forced blinking every 5 seconds) of normal subjects were $3.5 ± 2.2 (10^{-7})$ g/cm² per second and those of the obstructive MGD group were significantly higher, $5.7 ± 3.2 (10^{-7})$ g/cm² per second ($P = 0.001$). The flip height–evaporation rate ratio was 61.55% in normal subjects and 77.18% in the obstructive MGD group, respectively.

Discussion

This study reports a new tear evaporation system that uses microbalance technology, which accurately and sensitively detects changes in humidity at a high sampling rate (0.25 seconds) with sophisticated software, and its application to patients with obstructive MGD. This new method for the first time shows dynamic changes in tear evaporation in response to blinking as flip heights, which was analyzed to indicate the differences between normal subjects and patients with obstructive MGD. The results are shown on a computer display by real-time processing. The new method noninvasively generates additional information on the formation and dynamics of the aqueous tear and lipid tear layer. Both the real-time tear evaporation profiles (Figs. 2, 4) and dynamic changes in re-
response to blinking (flip heights) are advantages of this system over those described in previous reports (summarized in Table 1) to indicate the tear film stability.1–6 As shown in Figures 2, 4A, and 4B, during forced blinking, regular flips of frequency appeared on the profile at a steady state at the same intervals as the blinks. These results indicate that our evaporimeter can detect dynamic changes in blinking, especially in patients with obstructive MGD.

The tear evaporation profile showed that the new measurement system could detect rapid dynamic changes in tear evaporation rates in response to blinking after reaching a steady state. It took approximately 10 seconds to reach a steady state with minimal gas flow, after which flips appeared with blinking.

Significantly increased tear evaporation rates were reported in the obstructive MGD group (Fig. 5A). Patients with MGD have been reported to have poor lipid levels and higher evaporation rates (Table 1).1,2,22,23,35 Because we compared the two groups with normal Schirmer test results, these evaporation rates can be considered a direct representation of a function to limit evaporative tear loss in the ocular surface environment. Thus, our results indicated an insufficient amount and spread of tear lipid layer, which leads to abnormal evaporative tear loss and unstable tear film on the ocular surface of patients with obstructive MGD.

The flip heights in the obstructive MGD group were significantly higher than in the normal subjects (Fig. 5B). The flip height analysis measures dynamic changes in precorneal humidity as a result of blinking. If the subject has a normal lipid secretion and it spreads to cover the aqueous layer normally, evaporation rates measured in the eyecup remain stable during blinking. However, if the quality and/or quantity of tear lipid is inadequate, tear evaporation represented by flip heights are more unstable, decreasing with eye closure and spiking when the eye opens because the tear lipid layer is considered responsible for limiting evaporative tear loss and for stable precorneal humidity.7–11,39 The flip height–evaporation rate ratio, which indicates the ratio of change of tear evaporation by blinking in total tear evaporation, was 9% to 10% in our system setting. The ratio after the correction using the photographically measured ocular surface area increased to 60% to 80%, which appeared to be affected more by the actual exposed ocular surface area. Recently, Shine and McCulley40–45 have reported the abnormality in the quality of meibomian lipid in patients with chronic blepharitis. Such a qualitative lipid change may occur in the patients with obstructive MGD as well, and the role of this change with polar and nonpolar lipid composition to abnormal evaporative tear loss could be investigated with the combination of lipid analysis40–42,44,45 and clinical tear lipid evaluation22–25,30,34 including tear evaporation.

According to the regression analyses (Fig. 6), tear evaporation rates increased proportionally with the severity of meibomian gland obstruction. Under normal aqueous tear production with normal Schirmer test results, tear evaporation rates correlated with lipid tear status—that is, secretion, spread, and thickness of meibum.1,2,6,55 Flip heights and the severity of meibomian gland orifice obstruction were also found to correlate with lipid status. Thus, dynamic changes in tear evaporation appeared to reflect the severity of the obstruction. Tear evaporation rates and dynamic changes in them may well be affected by the amount of tear lipid on the lid margin and on the ocular surface.

Tear evaporation rates have been reported, by using several methods with different results and data (Table 1).1–6 We concluded that these differences are derived from the different methodology and system setup. Using the closed-chamber system, we have reported tear evaporation rates at 40% ambient humidity.1–3 In this report, we used the ventilated-chamber system with 10% to 15% humidity inside the eyecup. Also, we fixed the area of evaporation measurement, compared to that in previous studies, that calculated the area from the palpebral fissure.5,3 Strictly speaking, a method should be developed that measures the evaporation from the ocular surface alone. In this study, we also measured the area of exposed ocular surface and the size of palpebral aperture and tried to correct the tear evaporation rate by ocular surface area, but only in normal subjects. The relationship correlated well to findings in the report by Roland and Refojo.9 At this moment, to compare the tear evaporation rates between subjects or at a different point, it would be better to use the same system setup.

Our study also had some drawbacks. Accurate measurement of the dynamics of tear evaporation requires a quicker responding sensor, because lid blinking was more rapid than our sampling rate.36 However, if we had increased the sampling rate, reliability and accuracy would be lost.

For evaluation and quantification of aqueous and lipid tear production, this system is expected to be useful in combination with noninvasive (i.e., more reliable) methods, such as tear interference, and meibometry, and meniscometry to enhance the accuracy of dry eye diagnosis and classification.15,17,21,22

Our system noninvasively and easily measured ocular surface tear evaporation and its dynamics in response to blinking to show tear stability, and this facilitated differentiation of obstructive MGD from normal eyes, while indicating unstable tear film. This system is also expected to contribute to the evaluation of the treatment of obstructive MGD and evaporative dry eye.

References


