Quantitative Videographic Analysis of Blinking in Normal Subjects and Patients With Dry Eye

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Objective: To study patterns of eye blinking in normal subjects and patients with dry eye.

Methods: We developed an automated, noninvasive blink monitor that permits quantitative analysis of 6 parameters of blinking. We used this method under normal conditions and then examined the effects on the patterns of blinking in patients with dry eye; several steps in this method were designed to exacerbate or ameliorate ocular surface desiccation.

Results: The mean (±SD), maximum, and coefficient of variation of the interblinking time in normal subjects and patients with dry eye were 4.0±2.0 and 1.5±0.9 seconds, 8.9±4.0 and 4.2±2.4 seconds, and 55%±21% and 65%±24%, respectively. Those values for the blinking time were 0.20±0.04 and 0.27±0.16 seconds, 0.35±0.12 and 0.99±1.30 seconds, and 23%±9% and 46%±34%, respectively. The use of artificial tears or spectacles with moist panels and moist inserts tended to normalize the patterns of blinking in the patients with dry eye, whereas exposure to wind made them more abnormal.

Conclusions: Our technique permitted a rigorous analysis of blinking that was previously unavailable. We have shown that local ocular surface conditions alone can significantly affect patterns of blinking. This method should be applicable to studying psychologic and any other factors that may influence blinking.

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A PATTERN of blinking is often considered to be associated with an emotional state or psychologic conditions. Frequent blinking gives the impression of nervousness or abnormality, while decreased blinking is also thought to be abnormal. Indeed, increased rates of blinking in patients with schizophrenia[1,2] and decreased rates of blinking in patients with parkinsonism[3] have been documented. Moreover, central-acting dopamine is a key factor that controls blinking.[2,4-6]

However, local ocular surface conditions also affect the pattern of blinking. Normal blinking is an essential, involuntary action for the protection of the ocular surface.[7-10] Tear aqueous, mucin, and lipid components are spread with each blink. Preliminary work in the laboratory of Tokyo Dental College, Japan, has shown that the rate of blinking and the exposed ocular surface area are the main determinants of surface moistness.[11] In patients with dry eye, the rate of blinking increases to compensate for tear instability or deficiency. Since the incidence of dry eye, blepharitis, and allergic conjunctivitis that affects the ocular surface is high,[12,13] the increased rate of blinking may more often reflect compensation for a compromised ocular surface than betray an emotional or a psychologic condition.

Our previous study was limited in that we only counted the rate of blinking for a short period on a videotape.[11] To confirm our theory further that local conditions affect patterns of blinking, we have developed an automated blink analyzer. This noninvasive device examines a videotaped image, providing information about not only the rate of blinking but also other factors that have not been previously investigated. In particular, we analyzed 6 parameters: mean interblinking and blinking times (IBTs and BTs), maximum IBTs (Max IBTs) and maximum BTs (Max BTs), and coefficient of variation

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MATERIALS, METHODS, AND SUBJECTS

BLINK ANALYZER

The blink analyzer determines whether the eye is open or closed by evaluating the videotaped image brightness of the eye and eyelid. The image is brighter when the eye is closed and darker when the eye is open, because the eyelid reflects relatively more light, while the iris and pupil absorb more.

The blink analyzer consists of the following parts: a charge-coupled device camera videotape recorder, a digitizer, a computer, a computer display, a printer, and a keyboard (**Figure 1**). The charge-coupled device camera is sensitive to near-infrared radiation, and it uses an infrared light-emitting diode as a light source, thereby permitting the pattern of blinking to be studied under both dark and bright conditions. The computer program offers tracking ability, so that the analysis is performed automatically once the frame is fixed on the eye. The digitizer converts the analog signal of the videotape recorder to digital form, from 0 (black) to 255 (white), with a range of 0 to 80 considered dark and 81 to 255 considered bright. After initial analysis, the eye image was reproduced by using only dark and bright dots (**Figure 2**), with the latter representing the iris and eyelashes. Since the Japanese videotape system follows the National Television Committee Standard, the usual sampling rate is 30 per second. We modified this and made it possible to sample 60 images per second by using only half of the information to obtain 1 image. A typical blink is shown in **Figure 3**. There were 60 images per second, and the height of the bar shows the dark area. When a blink occurred, the height of the bar decreased and returned to its original level within 0.2 seconds. We defined the start of the blink as when the height of the bar changed more than 15% in 60 images per second and the end of the blink as when the height of the bar returned to baseline. However, it was impossible to detect unequivocally the absolute starting point, because small fluctuations (<5%) in the height of the bar were observed even when the eye was open.

ANALYSIS OF BLINKING

The recorded images were analyzed for 90 seconds for each patient. The blink analyzer calculated the following 6 parameters: (1) mean IBT, (2) mean BT, (3) Max IBT, (4) Max BT, (5) CV of IBT, and (6) CV of BT. These parameters are defined as follows: (1) mean IBT—the mean time from the end of the blink to the start of the next blink, (2) mean BT—the mean time from the start to the end of 1 blink, (3) Max IBT—the longest observed IBT during measurement, (4) Max BT—the longest observed BT during measurement, (5) CV of IBT—the SD of the mean IBT divided by the mean IBT (this reflects the irregularity of the pattern of blinking), and (6) CV of BT—the SD of the mean BT divided by the mean BT (this reflects the irregularity of the blink itself).

MEASUREMENTS OF BLINKING

The subjects were allowed to relax in a chair, and they were asked to look at the videotape camera, which was placed 3 m away. The subjects were not notified that the test was performed to analyze their blinks, so as not to influence their natural pattern of blinking. The brightness of the room ranged from 390 to 420 lux, the temperature was 22.2°C, and the humidity was 40%. There was no noise or measurable airflow inside the room during the measurements. The patients were videotaped for at least 3 minutes, with the middle 90 seconds used for analysis. Sample analyses that lasted from 10 to 180 seconds indicated that 90 seconds yielded consistent averages with regard to the parameters of blinking. A recording that was either too short or too long and the analysis times risked confounding factors that could have affected the data. For the same reason, all measurements were taken in the morning.

NORMAL SUBJECTS AND PATIENTS WITH DRY EYE

Sixty-four normal subjects (35 men and 29 women; age range, 20 to 51 years; mean±SD average age, 31.2±7.6 years) were recruited for the study. They had no eye disease, except low myopia (<−2.0 diopter). Fifty-one patients with dry eye (10 males and 41 females; age range, 12 to 79 years; mean±SD average age, 47.9±16.7 years) whose conditions were diagnosed according to the criteria of Toda et al[14] and Toda and Tsubota[15] were studied. Since preliminary studies revealed no correlation between age or sex and the parameters of blinking, the groups of normal subjects and patients with dry eye were not age- or sex-matched.

EFFECT OF OCULAR SURFACE CONDITION ON PATTERN OF BLINKING

To measure the effect of local ocular surface conditions on the pattern of blinking, we performed several additional measurements. We blew wind (0.90±0.05 m/s) into the faces of 36 patients with dry eye (6 males and 30 females; mean±SD average age, 49.5±15.9 years) to examine the effect on the pattern of blinking with regard to increased tear evaporation and desiccation. Spectacles with side covers and moist inserts are supposed to increase the humidity that surrounds the eyes and to decrease the tear evaporation,[16,17] and this perhaps stabilizes blinking; we studied 17 patients with dry eye (1 male and 16 females; mean±SD average age, 57.8±11.4 years) who wore such devices. The effect of both the spectacles and the wind was also evaluated (1 male and 14 females; mean±SD average age, 57.7±12.1 years). Finally, we examined the effect of artificial tears (IRIS CL-1, Taisho Pharmaceutical Co Ltd, Tokyo, Japan) on patients with dry eye (1 male and 10 females; mean±SD average age, 55.7±10.5 years), by instilling 1 artificial eye drop before videotape recording. These artificial tears were composed of sodium chloride (0.75 wt/vol%) and potassium chloride (0.09 wt/vol%), and these artificial tears contained no preservatives.

STATISTICAL ANALYSIS

The correlation coefficients among the parameters of blinking and the experimental conditions were calculated with a statistical software package (SAS, Statistical Analysis Systems, SAS Institute Inc, Cary, NC), with statistical significance determined by the Student t test.

(CV) of IBTs and BTs under both normal and stressed conditions.

RESULTS

PATTERN OF BLINKING IN NORMAL SUBJECTS AND PATIENTS WITH DRY EYE

The typical pattern of blinking in normal subjects is shown in **Figure 4**, left. A stable rhythm of blinking was noted under normal conditions. The overall average of the mean IBT in 64 normal volunteers was 4.0±2.0 seconds, with an average Max IBT of 8.9±4.0 seconds and an average CV of 55%±21%. The average mean BT in this group was 0.20±0.04 second, with an average Max BT of 0.35±0.12 second and an average CV of 23%±9%. Since 1 complete blink consisted of the IBT plus the BT, the average time used for 1 blink was as follows: 4.0+0.2=4.2 seconds. In 1 minute, 14.3 blinks (ie, 60/4.2 seconds) were observed, with a total IBT of 57.1 seconds (95.2%) and a total BT of 2.9 seconds (4.8%). Although females tended to blink more than males, there were no significant differences between males and females in any of the 6 parameters (**Table 1**), nor were any of the parameters correlated with age.

The typical pattern of blinking in patients with dry eye is shown in Figure 4, right. The 6 parameters of blinking were calculated in patients with dry eye and compared with those in normal subjects. The average mean IBT for 51 patients with dry eye was 1.5±0.9 seconds ($P<.001$), with an average Max IBT of 4.2±2.4 seconds ($P<.001$) and an average CV of 65%±24% ($P<.05$). The average mean BT in this group was 0.27±0.16 second ($P<.01$), with an average Max BT of 0.99±1.3 seconds ($P<.01$) and an average CV of 46%±34% ($P<.001$). All 6 parameters were significantly different from those in the normal subjects (Table 1). The time that was required for 1 blink in patients with dry eye was as follows: 1.50+0.27=1.77 seconds—this yielded a blink frequency of 60/1.77=33.9/min, with a total IBT in 1 minute of 50.8 seconds (84.7%) and a total BT of 9.2 seconds (15.3%). Patients with dry eye blinked more, and the total IBT was smaller than normal; thus, the ocular surface in patients with dry eye was covered longer by the eyelids. As in the group of normal subjects, sex and age had no significant effect on the parameters of blinking (data not shown).

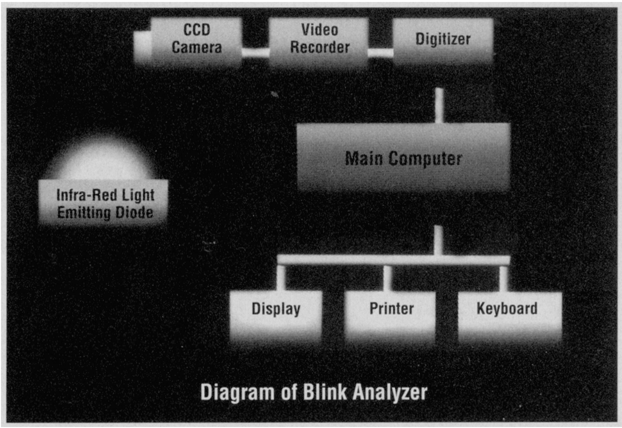

Figure 1. *Diagram of the blink analyzer. The videotaped image is processed and analyzed by the computer. CCD indicates charge-coupled device.*

EFFECT OF OCULAR SURFACE CONDITION ON PATTERN OF BLINKING

The 6 parameters of blinking before and after exposing the patients with dry eye to wind are shown in **Table 2**. The mean and Max IBTs were significantly decreased, while the mean BT was significantly increased; this exacerbated the already abnormal pattern of blinking in the patients with dry eye. There were no changes in the Max BT. The time that was required for 1 blink with the wind was as follows: 0.97+0.29=1.26 seconds (while frequency of blinking was 47.6/min). The total IBT in 1 minute was 46.2 seconds (77%), and the total BT was 13.8 seconds (23%). The wind shortened the time during which the eyes were open, with almost one fourth of the time spent actually blinking.

The wearing of special dry eye spectacles, as expected, caused the opposite effect on the pattern of blinking. The mean IBT was increased, while the mean and Max BTs were decreased (Table 2). The CV of the mean BT also was decreased; this finding demonstrated the stabilizing effect on the pattern of blinking by wearing pro-

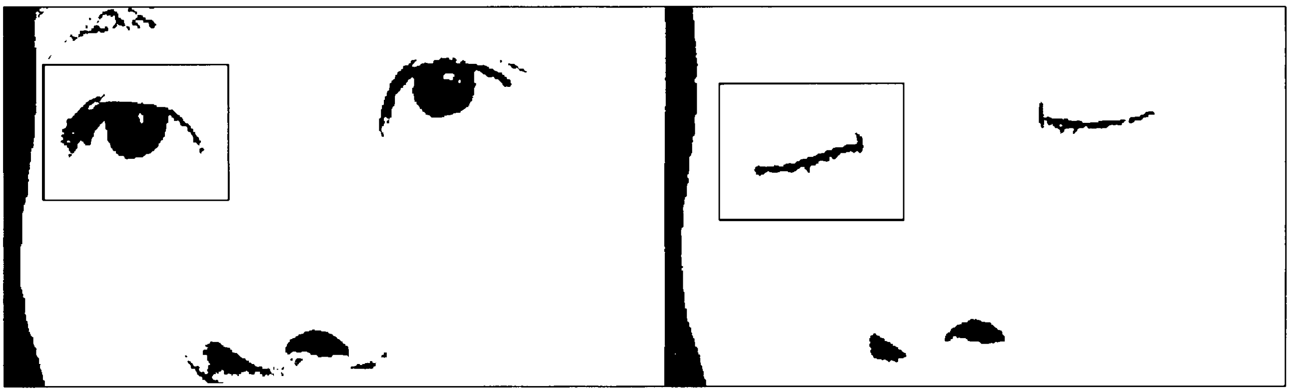

Figure 2. *Computer-processed images of open (left) and closed (right) eyes. The image is composed of black-and-white dots, with the black area in the square representing the parameter.*

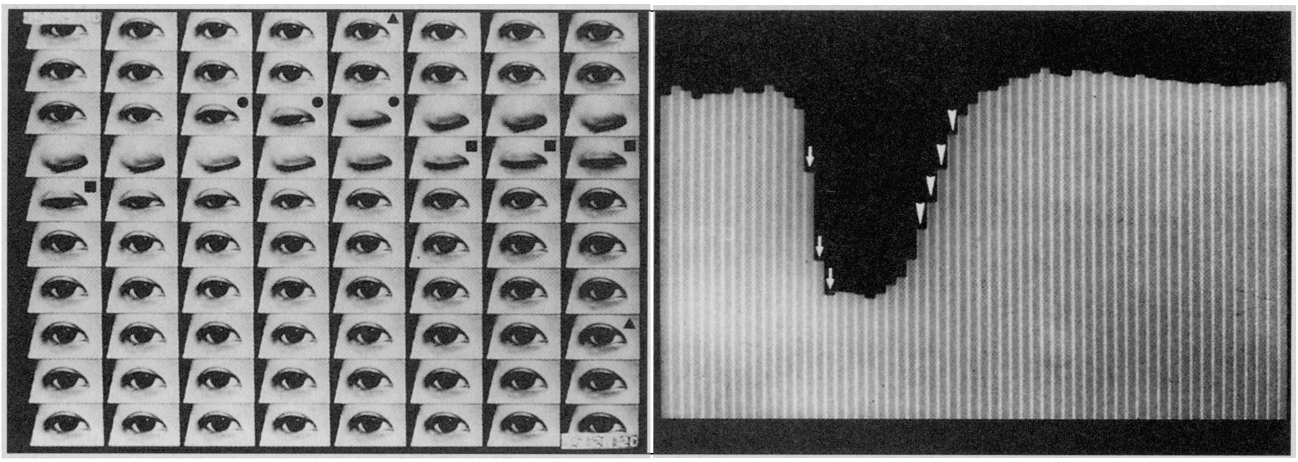

Figure 3. Left, Sequence of 80 images of an eye. There are 60 images per second, and the 80 images start at top left. The computer analysis (right) starts at the first triangle mark (image 5) and ends at the second triangle mark (image 64). The blink starts at image 19 (circle mark, third row, third column) and needs 3 columns to close the eye (images 19 through 21). The closing position lasts for 8 images (images 22 through 29), and the opening of the eye starts at image 30 (square mark, fourth row, sixth column) and ends at image 33 (square mark, fifth row, first column). The total number of images for a blink needs 15 images, which is 0.25 second. Right, Computer analysis of the left part (from image 5 to image 64). The height of the bar corresponds to the black area. Each column represents 60 images per second. The blink starts at the 15th bar and ends at the 29th bar. From our definition of a blink on the computer program, the first bar with a 15% decrease of height is recognized as the first step of a blink, and it is recognized as the end of a blink when the height returns to the height of the first blink. Three arrows indicate the closing movements of the eye; 4 arrowheads, the opening movements of the eye. The total bars needed for the blink are 15; thus, the blink time is calculated as 0.25 second.

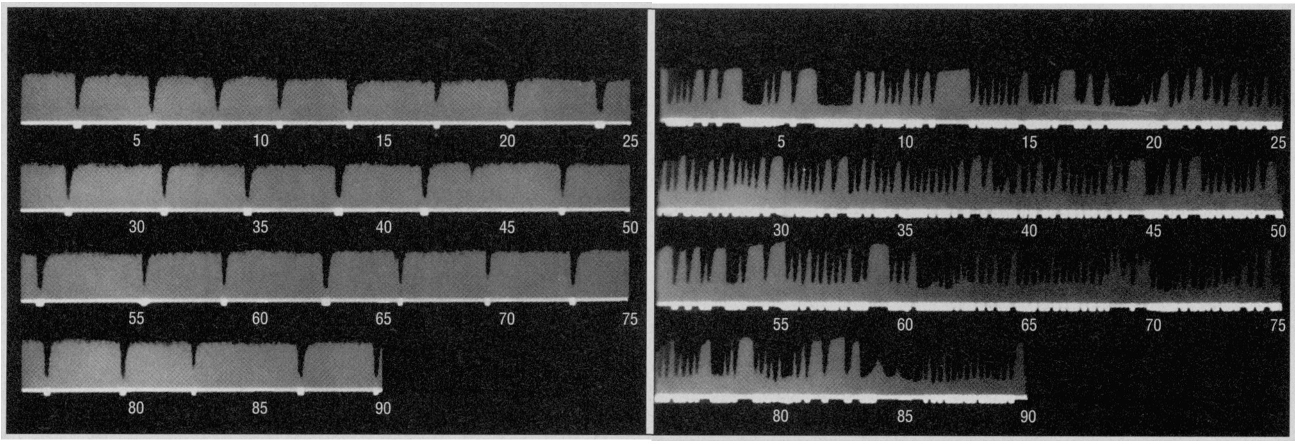

Figure 4. Typical pattern of blinking in normal subjects and patients with dry eye. Left, Analysis of blinking during 90 seconds for a 26-year-old man. The numbers that are shown are the seconds from the initial point. The upper level reflects the open eye condition, while the lower represents each blink. Note the regularity of the blinks (mean interblinking time [IBT], 3.27 seconds; maximum IBT, 5.33 seconds; coefficient of variation [CV] of IBT, 20%; mean blinking time [BT], 0.23 second; maximum BT, 0.33 second; and CV of BT, 20%). Right, Analysis of blinking in a 44-year-old woman with severe dry eye. Note the abnormally high frequency of blinking (mean IBT, 0.22 second; maximum IBT, 1.97 second; CV of IBT, 95%; mean BT, 0.32 second; maximum BT, 1.97 second; and CV of BT, 83%).

tective eyeglasses. The frequency of blinking was as follows: 60/(1.7+0.23)=31.1/min. Without the wearing of spectacles, the frequency of blinking was as follows: 60/(1.3+0.28)=38.0/min. The total IBT in 1 minute with and without the wearing of spectacles was 52.9 (88.2%) and 49.4 (82.3%) seconds, respectively, while the total BT in 1 minute with and without the wearing of spectacles was 7.1 (11.8%) and 10.6 (17.7%) seconds, respectively; these findings indicated that the wearing of protective spectacles increased the time during which the eyes were open and shortened the actual time of blinking. The combination of wind and spectacles yielded no significant changes, except for the decrease of the CV in the mean BT compared with the simple dry eye condition—probably because the 2 factors offset each other.

The use of artificial tears had the same effect as did the wearing of spectacles, namely, increasing the mean and Max IBTs and decreasing the mean and Max BTs; these findings reflected the stabilizing effect of artificial tears on the pattern of blinking (Table 2).

COMMENT

In this study, we used a newly developed automatic, noninvasive method to examine 6 parameters that characterized the pattern of blinking in normal subjects and patients with dry eye. We found that the pattern of blinking in normal subjects was stable and regular, with relatively low variation. In contrast, the pattern of blinking in patients with dry eye was more frequent and erratic. The fact that the latter individuals blinked more often under windy conditions and less often when they were wearing protective spectacles or using artifical tears in-

Table 1. Parameters of Blinking in Normal Subjects and Patients With Dry Eye*†

	IBT			BT		
	Mean, s	Max, s	CV, %	Mean, s	Max, s	CV, %
Normal subjects (n=64)	4.0±2.0†	8.9±4.0	55±21	0.20±0.04	0.35±0.12	23±9
Sex						
M (n=29)	4.1±2.4	9.2±4.2	58±24	0.21±0.05	0.34±0.11	21±9
F (n=35)	3.9±1.6	8.4±3.6	52±14	0.20±0.04	0.37±0.13	24±9
Patients with dry eye (n=51)	1.5±0.9	4.2±2.4	65±24	0.27±0.16	0.99±1.3	46±34
P‡	<.001	<.001	<.05	<.01	<.001	<.001

*IBT indicates interblinking time; BT, blinking time; Max, maximum; and CV, coefficient of variation.
†Values are given as mean±SD.
‡P value between normal subjects and patients with dry eye.

Table 2. Effect of Wind, Protective Eyeglasses, and Artificial Tears on Parameters of Blinking*†

	IBT			BT		
	Mean, s	Max, s	CV, %	Mean, s	Max, s	CV, %
Wind						
Without	1.6±0.9†	4.5±2.7	64±22	0.3±0.2	1.0±1.4	45±34
With	1.0±0.6	3.3±1.9	69±18	0.3±1.6	1.1±1.3	49±24
P	<.01	<.05	>.05	<.01	>.05	>.05
Eyeglasses						
Without	1.3±0.7	3.5±1.8	59±19	0.3±0.1	1.2±1.2	55±44
With	1.7±1.1	4.3±2.8	57±23	0.2±0.1	0.7±0.5	38±25
P	<.01	>.05	>.05	<.05	<.01	<.05
Wind, eyeglasses						
W(−)G(−)	1.1±0.7	3.7±1.9	69±29	0.3±0.1	1.2±1.2	55±45
W(+)G(+)	1.0±0.8	3.1±1.8	67±25	0.3±0.2	1.1±1.4	43±30
P	>.05	>.05	>.05	>.05	>.05	<.05
Artificial tears						
Without	1.2±0.6	3.9±2.2	65±0.2	0.3±0.1	1.6±1.3	71±0.5
With	1.8±1.0	5.5±3.1	66±0.2	0.2±0.1	0.6±0.3	35±0.2
P	<.05	<.01	>.05	<.05	<.05	<.05

*IBT indicates interblinking time; BT, blinking time; Max, maximum; CV, coefficient of variation; W(−)G(−), no wind and no eyeglasses; and W(+)(G+), with protective eyeglasses and exposure to wind.
†Values are given as mean±SD.

dicated that their frequency of blinking was primarily determined by the need to maintain the moistness of the ocular surface.

Frequencies of blinking have long been studied by ophthalmologists, neurologists, sociologists, and others. Ophthalmologists generally thought that the pattern of blinking was controlled by local mechanisms, while neurologists believed that the pattern of blinking was under more central neurologic control (eg, by dopamine).[2-6] The historic article by Ponder and Kennedy[18] indicated that the pattern of blinking was not controlled by the desiccation of the ocular surface because this pattern was not affected in a dry sauna where the humidity level was very low. Nonophthalmologists have discounted the role of ocular surface conditions, and they have emphasized the role of central and emotional factors in determining the patterns of blinking.[19] This is the popular notion, as was exemplified in a magazine article (*Newsweek*. October 24, 1988:11) that reported that the frequencies of blinking were 67/min for George Bush and 75/min for Michael Dukakis during their television debate for the 1988 US presidential campaign, suggesting that both candidates were under stress. Strong lights, the dry environment of the studio, and the local eye conditions of the 2 candidates were not considered. While psychologic states can certainly affect patterns of blinking, our study clearly shows that local ocular surface factors can play a significant role.

Among the normal volunteers, the average mean IBT was 4.0±2.0 seconds and the BT was 0.2 seconds, which means 14.3 blinks per minute. The BT time of 0.2 second was slightly shorter than that in the previous report by Doanne,[10] who found 257.9±11.3 milliseconds for the duration of blinking. This discrepancy may be owing to the definition of a blink that we have used and the method that we have used. The experiment of Doanne[10] might be able to detect the very initial phase of each blink. The average Max IBT was 8.0±4.0 seconds, with an average CV of 55%±21%; this indicates that while, on average, normal people need to blink every 8.0 seconds, there is a moderately large range. To our knowledge, we have performed the first rigorous measurement of BT, with an average of 0.20±0.04 second and an average Max BT of 0.35±0.12 second. Contrary to popular notion, there were no age or sex differences in the parameters of blinking. The total IBT and BT were 57.1 (95.2%) and 2.9 (4.8%) seconds, respectively, in 1 minute. During almost 5% of the time, Volkmann et al[20] reported that there was a suppression of the visual pathway associated with blinks that balanced the darkness that was produced by each blink.

In contrast, patients with dry eye blink more, with an average IBT of 1.50±0.88 seconds and BT of 0.27 second corresponding to 33.9 blinks per minute. The average Max IBT was reduced to 4.2±2.4 seconds, and the CV was increased to 0.65±0.24 second. Interestingly, the average BT was larger than normal (ie, 0.27±0.16 second). Since the use of artificial tears or the wearing of protective eyeglasses lowers the average BT, the increase in the BT is related to the desiccation of the ocular surface. Increased friction between the eyelid and the ocular surface may slow the movements of blinking. Furthermore, increased friction may have a deleterious effect on the ocular surface, especially with its considerable posterior force on the corneal surface with the absence of normal lubricity. The Max BT was 0.99±0.13 second, and the CV was increased to 46%±34%. These values and their variation were significantly different from those in the normal subjects; these findings were apparently entirely owing to local ocular surface conditions, specifically desiccation. Furthermore, the total IBT and BT were 50.8 (84.7%) and 9.2 (15.3%) seconds, respectively. Thus, patients with dry eye have their eyes closed more than 3 times as much as do normal individuals, which may have a salutary effect and reduce discomfort in the dry eye condition. Moreover, this relatively long period without visual stimulation may or may not be compensated for by the mechanism proposed by Volkmann et al.[20]

Exposure to wind increased the rate of blinking and the variability of the parameters of blinking, whereas wearing protective eyeglasses and using artificial tears had the opposite effect. The average BT and IBT values moved in opposite directions, according to the experimental conditions. The countervailing effects of the wind and the spectacles tended to negate each other. The wetting of the ocular surface stabilizes blinking, as manifested by increases in the mean and Max IBTs and decreases in the CV of IBT and BT and the mean and Max BTs.

We have developed a new quantitative method of analyzing the patterns of blinking and have identified 6 parameters of clinical relevance. We have shown that local ocular conditions alone can significantly affect those parameters (Table 2; Figure 4, right). A recent study of frequencies of blinking in users of video display terminals suggests that the pattern of blinking is important for the development of video display terminal syndrome.[21,22] Our automated, noninvasive technique should be valuable in assessing all factors that may affect blinking, including other environmental as well as nonenvironmental (including psychologic) conditions.

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