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Corneal temperature in patients with dry eye evaluated by infrared radiation thermometry

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Abstract

***Aims*—The corneal temperature change following each blink was investigated in patients with dry eye using an infrared radiation thermometer.**

***Methods*—Twenty patients with dry eye and 20 normal controls were enrolled in this study. Subjects kept their eyes open for 10 seconds without blinking and corneal temperature was measured every second with a recently improved infrared radiation thermometer.**

***Results*—In the 20 patients with dry eye, corneal temperature change after keeping the eye open for 10 seconds was 0·21 (SD 0·06)°C while it was 0·61 (0·28)°C in the 20 normal patients (p=0·0001). In an exponential equation, the inclination of the slope of a patient with dry eye was smaller than the normal. The correlation coefficient was *r*=0·79 (0·16) in patients with dry eye and *r*=0·90 (0·07) in normal patients. The mean K value of patients with dry eye was 0·20 (0·13)/second and that of normal subjects was 0·31 (0·19)/second (p=0·03).**

***Conclusion*—Findings demonstrate the usefulness of this thermometer for measuring corneal temperature in the evaluation of dry eye. Decrease in corneal temperature with each blink in patients with dry eye was smaller than in normal subjects.**

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Dry eye can be caused by a decrease in the amount or a change in the quality of tears[1–3]; it results in ocular irritation, foreign body sensation, and pain.[4] A normal tear film layer is essential for maintaining the integrity of the ocular surface.[5] In diagnosing dry eye, tear dynamics arc currently evaluated clinically by the Schirmer and cotton thread tests.[3 4 6 7] A new measurement of tear evaporation, the rate of tear evaporation from the ocular surface at 40% ambient humidity (TEROS 40) has also been used in the evaluation of the dry eye,[8] showing decreased TEROS 40 in dry eye. Since the evaporation of tears reduces the temperature of the ocular surface,[9] the temperature of a dry eye may be different from normal eyes. We measured the corneal temperature and investigated the corneal temperature change following each blink in patients with dry eye.

Materials and method

Table 1 Criteria for diagnosis of dry eye

Dry eye: 1+2 or 1+3, or 1+2+3	
1	Presence of chronic dry eye symptoms: foreign body sensation, irritation, ocular pain, dryness, other.
2	Positive result on vital staining test of the conjunctiva and cornea: Rose bengal score ⩾3 Fluorescein score ⩾1
3	Abnormalities in tear dynamics: Schirmer's test ⩽5 mm Cotton thread test ⩽10 mm Tear break up time (BUT) ⩽5 s Tear clearance test ⩽4×

Twenty Japanese patients with dry eye, 10 men and 10 women (age range 15 to 54 years, mean age 37·9 (SD 11·6) years) were evaluated, together with 20 normal control subjects, 10 men and 10 women (age range 23 to 60 years, mean age 35·1 (10·8) years). Informed consent for participation in this study was obtained from each individual. Dry eye was diagnosed according to the clinical criteria shown in Table 1.[4 11] Vital staining of the ocular surface utilised rose bengal and fluorescein. Rose bengal staining was graded from 0 to 3+ at the nasal conjunctiva, the temporal conjunctiva, and the cornea, with a possible total score ranging from 0 to 9+; values greater than 3+ were considered positive. Fluorescein staining of the cornea was graded from 0 to 3+; values greater than 1+ were considered positive.[1] Tear break up time (BUT) and Schirmer's test were performed as follows; BUT was positive below 5 seconds; Schirmer's test was performed 5 minutes after the instillation of a drop of solution containing 0·5% fluorescein

Figure 1 Infrared radiation thermometer THI-500. This device measures 14 cm in length, 6 cm in width, and 2·7 cm in height and weighs 265 g with the probe.

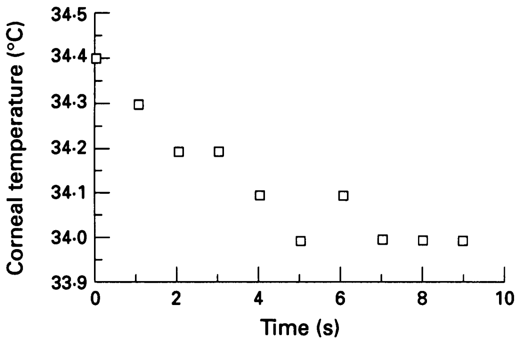

Figure 2 Corneal temperature of a normal male subject (33 years). Corneal temperature decreased, and then settled down to a constant value.

Table 2 Test results in 20 patients with dry eye

Patient	Age (age)	Sex	T_1 (°C)	T_∞ (°C)	T_1-T_∞ (°C)	K (/s)	r	TEROS 40 (R/L 10^{-7} g/cm²)
1	48	F	34·4	34·1	0·3	0·21	−0·89	8·15/9·22
2	26	M	34·1	33·9	0·2	0·21	−0·77	4·01/3·13
3	26	F	33·6	33·3	0·2	0·14	−0·71	5·13/7·12
4	48	F	34·3	34·2	0·1	0·07	−0·77	2·91/5·22
5	26	F	32·7	32·6	0·1	0·07	−0·77	2·99/2·73
6	43	M	34·6	34·4	0·2	0·21	−0·77	11·05/13·16
7	53	M	34·1	33·9	0·2	0·14	−0·71	8·49/9·01
8	54	F	34·6	34·3	0·3	0·07	−0·88	4·01/13·13
9	26	F	33·9	33·7	0·2	0·10	−0·85	4·37/8·89
10	43	M	34·1	33·9	0·2	0·04	−0·25	7·78/10·13
11	48	F	34·4	34·1	0·3	0·15	−0·77	11·96/13·99
12	24	F	33·8	33·6	0·2	0·27	−0·94	4·18/13·68
13	22	M	34·4	34·2	0·2	0·55	−0·99	4·45/5·37
14	15	M	34·1	33·9	0·2	0·14	−0·71	8·40/5·60
15	45	F	34·1	33·9	0·2	0·14	−0·71	10·75/9·51
16	41	M	33·9	33·8	0·1	0·33	−0·94	8·49/10·01
17	37	M	34·1	33·9	0·2	0·35	−0·87	11·05/13·16
18	41	F	32·8	32·5	0·3	0·16	−0·87	5·06/10·52
19	45	M	33·9	33·7	0·2	0·40	−0·95	7·15/8·03
20	46	M	33·9	33·7	0·2	0·14	−0·71	6·36/8·57
Mean	37·9		34·0	33·8	0·21	0·20	−0·79	6·84/9·01
SD	11·6		0·5	0·5	0·06	0·13	0·16	2·89/3·41

Table 3 Test results in 20 normal subjects

Patient	Age (age)	Sex	T_1 (°C)	T_∞ (°C)	T_1-T_∞ (°C)	K (/s)	r	TEROS 40 (R/L 10^{-7} g/cm²)
1	24	M	34·1	33·7	0·4	0·69	−0·99	10·54/21·89
2	52	F	34·3	33·4	0·9	0·27	−0·98	21·27/11·15
3	27	M	33·9	33·5	0·4	0·23	−0·86	14·87/16·71
4	28	F	34·2	33·5	0·7	0·35	−0·94	11·56/13·42
5	25	M	34·8	33·7	1·1	0·38	−0·95	15·81/14·72
6	60	F	34·2	34·7	0·5	0·17	−0·84	19·35/17·12
7	32	F	33·8	32·9	0·9	0·27	−0·98	12·43/12·65
8	23	M	35·3	35·0	0·3	0·22	−0·82	15·13/10·08
9	48	M	33·9	33·6	0·3	0·22	−0·88	10·49/12·66
10	24	F	34·4	33·9	0·5	0·13	−0·87	16·18/21·07
11	44	F	35·2	34·7	0·5	0·92	−0·91	18·89/13·13
12	28	M	33·9	33·6	0·3	0·32	−0·93	21·38/20·99
13	37	M	34·1	33·5	0·6	0·24	−0·89	14·13/9·89
14	29	F	33·8	33·4	0·4	0·16	−0·78	19·33/17·56
15	51	M	34·2	33·9	0·3	0·27	−0·95	15·54/10·06
16	33	M	33·9	33·5	0·4	0·23	−0·95	21·98/14·81
17	39	F	34·1	33·1	1·0	0·19	−0·90	11·82/8·83
18	34	F	33·9	32·8	1·1	0·48	−0·73	14·18/13·68
19	26	M	34·4	33·5	0·9	0·23	−0·96	15·62/17·49
20	38	F	33·8	33·2	0·7	0·24	−0·95	24·18/18·35
Mean	35·1		34·2	33·6	0·61	0·31	−0·90	16·23/14·8
SD	10·8		0·4	0·6	0·28	0·19	0·07	4·0/4·0

and 0·4% oxybuprocaine hydrochloride into the conjunctival sac, values less than 5 mm were considered positive.[3 4] Tear clearance was expressed by the colour of fluorescein on a paper strip and was graded as 1×, 2×, 4×, 8×, etc,[3] values less than 4× were considered abnormal. The patient's awareness of dry eye symptoms and at least one positive clinical variable led to a diagnosis of dry eye.

The evaporation of tears was measured by TEROS.[8] Normal controls had no symptoms of dry eye and no positive clinical variables.[4 10]

Measurements of central corneal temperature were made in a room with constant temperature (24·9 (0·52)°C), constant humidity (40% (5%)), and constant brightness. After 15 minutes at rest with normal blinking and then keeping their eyes closed for 10 seconds, the subjects kept their eyes open for 10 seconds without blinking; corneal temperature at the centre of the cornea was measured every second by the same instrument operator. Temperature was measured with a THI-500 (Tasko Japan, Osaka, Japan) non-contact infrared thermometer (Fig 1) that can evaluate temperatures between 0 and 300°C with a resolution of 0·1°C. Approximately 0·7 seconds was required for each measurement; thus we could measure the corneal temperature for every second. The measuring circle had a 0·9 mm diameter.

Preliminary measurement of central corneal temperature in dry eye and normal subjects did not show any differences. Thus we sought to determine whether the central corneal temperature decreases after blinking, which would reflect the tear condition. To measure ocular surface temperature, we used the THI-500 thermometer.[9 11–13] It was found that corneal surface temperature decreased rapidly when the eye was kept open, then settled down to a constant value (Fig 2). Consequently, corneal surface temperature was measured for 10 seconds after the initial opening of the eye and the temperature at this point approximated to T_∞. When $T-T_\infty$ was plotted against time t by use of an exponential equation, the graph proved to be linear and the relation could be described by the following equation: $T=(T_0-T_\infty)e^{-Kt}+T_\infty$ [T= temperature (°C), T_0=temperature before blinking, T_1=first recordable temperature on the corneal surface immediately on lid opening, therefore within 1 second after lid closure, T_∞=temperature at equilibrium, t=time in seconds, K=temperature coefficient]. In reality, it is impossible to measure T_0, so the first measurement made (T_1) was substituted for T_0. Thus, the equation becomes $T=(T_1-T_\infty)e^{-Kt}+T_\infty$. K is the slope of the regression curve of these data when they are plotted exponentially. The K values (/second) for all subjects were calculated and the two groups were compared.

Data are reported as mean (SD). Data were analysed by Student's paired *t* test. A level of $p<0.05$ was considered statistically significant.

Results

Mean corneal temperature in patients with dry eye was 34·0 (0·5)°C and that in normal controls was 34·2 (0·4)°C. These values are in good agreement with those previously reported.[14–16] There was no significant difference in corneal temperature between the dry eye and control groups (p=0·15). Mean values of Schirmer's test and the tear clearance test of patients with dry eye were 6·2 (3·3) mm and 18·6 (18·8) times, and those of normal controls were 13·4 (7·0) mm and 41·6 (19·7) times (right eye). Results of Schirmer's test

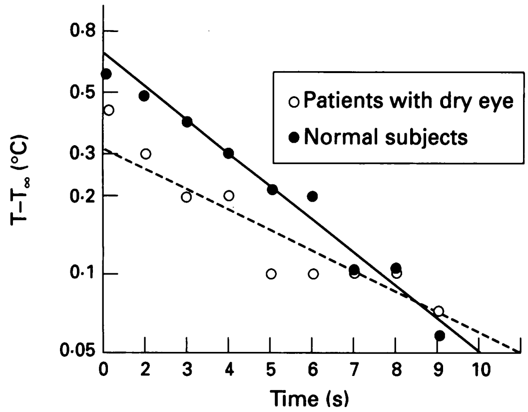

Figure 3 Corneal temperature upon opening the eye in one individual plotted exponentially. T_∞=temperature at equilibrium. The correlation coefficient is r=−0·79 (0·16) in dry eye patients and r=−0·90 (0·07) in controls. The slope of the line for temperature measurements of patients with dry eye is less steep than that for normal control values.

(p=0·0002) and the tear clearance test (p=0·0005) were significantly decreased, compared with controls. Tear evaporation (TEROS 40) for the right eye of patients with dry eye was 6·8 (2·9) compared with 16·2 (4·0)$\times 10^{-7}$ g/cm^2 for controls. Tear BUT for the right eye of patients with dry eye was 3·45 (1·40) compared with 6·35 (1·39) seconds for controls. Both tear evaporation and tear BUT of patients with dry eye were significantly decreased, compared with controls (p=0·0001) (Tables 2–4).

In 20 patients with dry eye, T_1 was 34·0 (0·5)°C and T_∞ was 33·8 (0·5)°C. In 20 normal subjects, T_1 was 34·2 (0·4)°C and T_∞ was 33·6 (0·6)°C. $T_1 - T_\infty$ (corneal temperature change 10 seconds after opening the eye) was 0·21 (0·06)°C, compared with 0·61 (0·28)°C in 20 normal subjects (p=0·0001). The magnitude of change of corneal temperature was significantly greater in normal than in dry eyes (Tables 2–4). There were correlations between $T_1 - T_\infty$ and the results for the right eye of Schirmer's test (p=0·0001), TEROS 40 (p=0·0002), and tear BUT (p=0·004), but not age (p=0·6) or clearance test (p=0·28).

In a typical patient with dry eye, central corneal temperature decreased only briefly after the eye was opened; in a normal subject it continued to decrease. In the plot of an exponential equation, the slope of the line for temperature measurements of patients with dry eye was less steep than that for normal control values (Fig 3). The correlation coefficient was *r*=−0·79 (0·16) in patients with dry eye and *r*=−0·90 (0·07) in normal patients (Tables 2 and 3). There was a strong correlation that was mathematically significant. When the slope K, of the equation $T=(T_1 - T_\infty) e^{-Kt}+T_\infty$ was measured, the K for patients with dry eye was 0·20 (0·13)/second and that for normal controls was 0·31 (0·19)/second (Tables 2–4) (p=0·03).

Discussion

This study demonstrated the usefulness of infrared radiation thermometry in evaluating patients with dry eye. Corneal temperature was measured,[9 11–16] and we found that the corneal temperature decreases after each blink and the rate of decrease was smaller in patients with dry eye. Although the TEROS 40 method is complex as well as being costly, measurement of temperature itself is inexpensive and its usefulness has been reported in evaluating inflammation after cataract surgery.[13]

Tear production decreases with increasing age. Our two study groups showed no significant age difference and had no correlation with T_1-T_∞. Measuring tear flow is a common way to diagnose dry eye. Schirmer's test,[3 4] the cotton thread test,[6 7] and a new technique, TEROS 40,[8] are currently used as diagnostic methods. Measuring the corneal temperature was also found to be available. The significance between dry eye and normal was below 0·05, a level that exceeded that which was obtained with the Schirmer's test and TEROS 40 test, but there was a good correlation between $T_1 - T_\infty$ and Schirmer's test BUT, and TEROS 40 test. While we mentioned that this technique is 'easy', there were still a lot of technical difficulties encountered in taking corneal temperatures – keeping the distance of the probe from the eye, steadiness of the examiner's hand, wind or moisture currents, and stability of readings. Improvements such as measuring at shorter time intervals, sensitivity, or smaller surface areas are needed to measure the small changes.

While these measurements are necessarily rough because the instrument has a resolution of 0·1°C, and the maximum decrease in the patients with dry eyes was only 0·1 or 0·2°C in 16 cases out of 20, ocular surface temperature decreased after opening the eye in this study. As the temperature we measured in this study

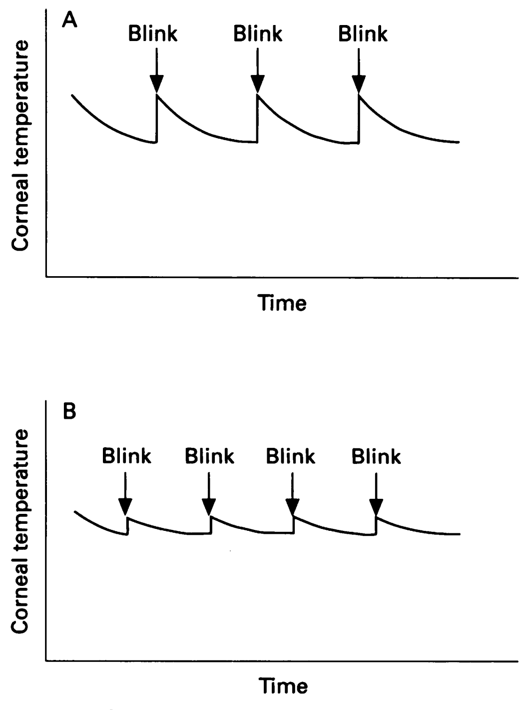

Figure 4 Corneal temperature after every blink (an imaginary figure). Corneal temperature decreases with every blink in normal subjects (A), but has smaller change in patients with dry eye (B).

was the change in temperature after the first 10 seconds, we presume this change of ocular surface influences the blink. The blink time is much shorter than the time the eye is opened, however, and this change in the temperature of the ocular surface may contribute to the mechanisms of eye blink, and to the syndrome of dry eye (Fig 4).[15 24–26] Corneal temperature is significantly affected by tear evaporation and may change with every blink. Because of reduced evaporation, corneal temperature in patients with dry eye is stable and shows a small change after each blink.

Cooling of the cornea is known to produce comfort,[27] thus a stable corneal temperature may contribute to the discomfort in the patients with dry eye. In other words, fluctuation of corneal temperature may be necessary for the comfortable feeling in normal eyes. Application of eyedrops relieves the burning sensation of dry eye for a short period of time. This may be because of the temperature fluctuation on the cornea after instillation of an eyedrop. The relation between blinking and the temperature of the ocular surface, including the time between blinking, interblink time (IBT), requires further study.[28]

With further study and development, use of infrared radiation thermometry may prove to be an effective clinical procedure for diagnosing dry eye. It may also yield additional information about ocular surface tear dynamics related to blinking.

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